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SOIL-FERTILITY MAINTENANCE UNDER DIFFERENT SYSTEMS OF AGRICULTURE

H. L. RICHARDSON[1]

In this paper the writer examines the degree to which fertility is maintained or lost under various existing systems of agriculture; in a second paper he hopes to discuss the best ways of improving soil fertility in the future. Doubtless much of the material included is already known, but the whole question of maintaining soil fertility is so complex, and so much has been written about it from local or partisan points of view, that a balanced survey of the whole problem seems to be called for. It would require a book, with a large bibliography, to cover the subject adequately, so what follows will have to be highly selective. No attempt is made at completeness of reference to the literature, but emphasis is given to outstanding aspects that have come under the writer's own observation and experience.

The term 'soil fertility' has been used in various senses, most generally to express the fruitfulness or productivity of the soil [1]. In the present paper the words 'fertility' and 'productivity', as applied to soil, may be taken as synonymous. The many factors involved in soil fertility are fully discussed in the text-books (e.g. E. J. Russell [2]); the chief are water-supply, nutrient-supply (including both major and minor elements), soil reaction, organic-matter content, texture, structure and tilth, aeration and waterlogging, depth of top-soil and nature of profile, and the occasional presence of injurious substances; and to these must be added temperature, length of day and of season, crop variety, and pest or disease attack. To attempt to keep all these factors isolated in the mind while discussing soil fertility would involve a major dialectical exercise, but this is not necessary provided that their existence is not forgotten.

Particular attention will be paid in these papers to the *edaphic* factors that appear chiefly to be limiting growth under any given circumstances, on the assumption that the other environmental factors are not too far from the optimum for the crop or the variety concerned—which is likely to be true for any of the chief crops in the areas where they are widely grown. In the second paper the importance of the water-supply will be brought to the fore. In this paper most attention will be given to manuring and soil management, because if all the other factors are attended to, and yet the plant-food supply in the soil is deficient, the soil remains infertile; and all the cultivation, plant-breeding, pest control, and so on

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that can be done are of little effect. This conclusion has been reached, for example, by research workers on the starved soils of India.

An aspect of soil fertility, of great practical importance, is whether the soil contains large reserves of plant-nutrients that can become available under continued cultivation. A soil containing large reserves of fertility can be cropped continuously, without much need for manuring or complicated rotations, and it will continue for a long period to give yields as high as the local climatic conditions will permit; for example, the best of the steppe or prairie soils of Russia and North America. But there are many other soils which may give high yields when freshly broken in, or when freshly manured, yet whose yields rapidly decline under continuous cultivation without manuring.

Broadly, one may say that the 'pedocal' soils of Marbut's classification tend to have large reserves of fertility, whereas the reserves of the 'pedalfer' soils are low. (Pedocals are distinguished by the accumulation of carbonate of calcium in all or a part of the soil profile. Pedalfers are distinguished by the absence of carbonate of lime accumulation and usually by an accumulation of iron and aluminium compounds; they are the typical soils of humid regions [3].) It is soils of the latter class which are likely to require special care and attention to maintain their fertility, by manuring, rotations, mixed farming or alternate husbandry, and other means to be described. Good farming under these conditions aims not merely at securing a large crop for one year or two, but at building up the fertility reserves in the soil: as an English farmer would say, 'Get the land into good heart'. This is most readily done, in practice, by increasing the organic-matter content of the soil, and it is for this purpose, even more than for their immediate nutrient or physical effects, that bulky organic manures are to be valued.

Natural recuperation.—In the account that follows reference is made to the 'natural recuperation' of soil fertility, a concept, much favoured in India, which connotes that nitrogen fixation, both by free-living micro-organisms and by the root-nodule bacteria of legumes, counteracts in some degree the natural losses of nitrogen that take place in soils or replaces nitrogen removed in crops. At the same time, mineral plant-nutrients present in the insoluble soil minerals slowly become soluble or available to plants as a result of weathering. If little is being removed from the soil, as under jungle, wild grassland, or careful grazing, the fertility status of the soil may actually increase by natural recuperation; but if the soil is being continuously cropped, the rate of natural recuperation is sufficient only to maintain crop yields at minimal levels.

Signs of low fertility.—Stunted growth and sparseness or thinness of the crop are, of course, indications of an infertile soil. Another sign, useful in practice because it is so easily recognized, is a marked patchiness or variability in the height and growth of the crop in a field. In contrast, a fertile and well-manured field gives a crop that is not only tall and dense but of even growth. Where animals are used for cultivation, infertile soils often show striking spots of heavy, green growth, due to the excreta dropped by the work animals; these in themselves indicate the extent to which yields might be improved by manuring. Where

nitrogen is a limiting factor, the pale, yellowish-green colour of the growing crop is often unmistakable, and there are many other signs of specific nutrient deficiencies now recognizable [4, 5].

Fertility of natural soils.—This is often overrated by sentimental and popular writers. The word 'natural' carries no magic with it, and natural conditions and processes may be bad or deleterious as well as beneficial. Many soils in the natural condition support a very poor vegetation and have very limited possibilities for cultivation. There are heaths, swamps, peat-bogs, and tundra; scrub associations; deserts and arid regions; mountains and steep hill-sides: they are all 'natural', and in sum they occupy a large proportion of the earth's surface; yet they are anything but fertile. Indeed, Fawcett [6] has estimated that of the 56 million square miles of the earth's land surface, 22 million, or 40 per cent., are too cold or too dry to support crops, whilst of the remaining 60 per cent., half consists of poor grazing land, uncultivable forest, marsh, waste, or high mountains. Thus less than one-third of the land surface may be considered cultivable, or relatively fertile under natural conditions.

Even when the soil supports a heavy vegetation in the wild state, its reserves of fertility are often small. Wild vegetation exists in a closed cycle: quite a thin skin of top-soil may be present, slowly used over and over again as the trees and other plants grow and decay; once the cycle is broken by felling the trees and taking crops or grazing off the land, it may be only a very few years before the scanty fertility reserves are exhausted if fertilizers are not used. Such experience is general, in fact, wherever virgin soils of the podzolic or red-earth zones are brought under cultivation [7]. Sometimes an apparently fertile soil may reveal its low fertility status under natural conditions; for example, when some of the giant kauri (*Agathis australis*) forests in New Zealand were destroyed by storm or fire, nothing could follow them but a heathy vegetation of manuka (*Leptospermum scoparium*) scrub, because the kauri pine had produced such severe podzolization of the soil.

Probably the most fertile natural soils are those of grassland associations existing under moderate to light rainfall, an observation not without interest in relation to the value of grasses, grown in rotations, for improving the fertility status of cultivated soils generally. For further information on the fertility of natural soils, as well as on the problems of maintaining fertility in modern agriculture, reference may be made to a valuable, though brief, paper by E. M. Crowther [8].

Fertility Maintenance under Different Systems

(*a*) *Primitive agriculture.*—By this term is understood the agriculture or gardening of primitive tribes; it links up with the first attempts at agriculture made by neolithic man.

There is such diversity in the agriculture of primitive peoples that it cannot fairly be summarized in a paragraph; the references following give accounts of tribal agriculture in Africa [9], in India [10], and in the South Pacific [11, 12]. A constant feature of most primitive systems is shifting cultivation, which, it has well been said, 'is only adopted

because the agricultural system cannot maintain the fertility of the land with continuous cultivation' [13].

Under shifting cultivation the limited fertility reserves of forest, jungle, or scrub soils are utilized; they are exhausted (erosion being a factor) during the first few years after clearing, and the land is then abandoned and allowed to run wild, while another patch elsewhere is cleared. After quite a long period of years under jungle, during which some recuperation of soil fertility takes place, the whole cycle is repeated. The land receives some potassic manuring from the ashes left when the jungle is cleared and burned; but magic usually plays a larger part than manuring in the attempt to maintain soil fertility by primitive peoples. The system is, on the whole, one of mining the fertility of the soil, and average yields are low. Further, most of the land is unproductive for most of the time. This may not have mattered when the population was small relative to the areas of land available for cultivation, but it becomes a subject for serious concern with the rapidly increasing populations of the present day.

Some primitive agriculture is at a higher level than this, particularly the methods used by those tribes who cultivate vegetable and fruit gardens. These gardens are usually located so that the natural conditions are suitable for fertility maintenance, on level land or hollows with soils rich in humus. Some kind of manuring may be employed, e.g. bringing in fertile soil from elsewhere, or gravel to lighten the texture of the soil, or leaf mould; also using excrement, ashes, and sacrificed animals.

(*b*) *Traditional agriculture.*—This differs from primitive agriculture, as here defined, in that large-scale continuous cultivation has replaced shifting cultivation; improved agricultural techniques were evolved as primitive man progressed from the stage of a 'culture' to that of a 'civilization'. Traditional agriculture persists until the present day in those partly developed countries where modern scientific agriculture has not yet been adopted. Peasant farming is typical of traditional agriculture, although some peasants still use shifting cultivation (e.g. in south China and in the West Indies [13]), and in many parts of the world peasants are now adopting scientific methods.

Magic or religious ritual still figures largely, whilst methods of soil-fertility maintenance or replenishment by manuring are sometimes, though not always, employed. Traditional agriculture differs from modern agriculture not only in technique, but in the large labour requirements of the system, and in the low efficiency of output of the labour. Under the major heading one may distinguish various important subdivisions, the chief of which follow. The historical study of the development of different kinds of traditional agriculture is a fascinating subject about which, however, little can be said here.

Egypt.—Soil fertility has been maintained here for fifty or sixty centuries; this has depended on the high initial fertility of alluvial soils and on the annual addition of fresh reserves of plant-food in the silt or mud carried in irrigation-waters. There was careful control of the flood-waters of the Nile so that the water, and the silt, would be spread over

every field. Some inadvertent manuring from grazing animals and human excreta may have occurred in the fields near villages, but it does not seem that systematic manuring was employed until recently. Soil fertility was maintained at a moderate rather than a high level: the average yield of wheat in Egypt for the years 1909–13 (before much artificial fertilizer was used) was 25 bushels per acre; and Nile valley soils have been found to be very responsive to fertilizers [14, 15].

Other early valley-plain civilizations, including those of Mesopotamia, were rather similar to that of Egypt in the matter of soil-fertility maintenance, though they may have differed in detail or in subsequent development. Indeed, it was the existence of conditions naturally suitable for soil-fertility maintenance under continuous cultivation that enabled the first civilizations to evolve in these valley plains.

The Mediterranean.—Many causes have been given for the rise and fall of the various civilizations—Cretan, Phoenician, Grecian, Roman, Carthaginian, and others—around the Mediterranean. One important cause may well have been that they tried to imitate the Egyptian system of continuous agriculture in unsuitable environments where there was no replenishment of soil fertility by river silt. On the generally hilly land occupied by these nations, both erosion and soil exhaustion must proceed rapidly under continuous cropping; and this would, to say the least, add to the difficulties of a nation that was already having troubles of a military or social nature. Certain improvements in the agriculture of hilly land were gradually evolved; level bench terracing, for example, was done to check erosion and to retain any elements of fertility added in manures. Lowdermilk has pointed out (in a lecture) that some of the terraced fields found in Asia Minor to-day were probably constructed by the Phoenicians four or five thousand years ago; and, indeed, the terracing of hill-sides is typical of the Mediterranean agriculture which has survived to the present time.

Manuring was already used in Greek [16] and Roman times, and the Roman writers have much to say about the different kinds of local manures and their uses, referring particularly to cattle manure, green manure, and lime [2, 17, 18]. Such materials have continued in use ever since, but, except in central Italy [19], human excreta have not been much employed in the Mediterranean region. More recently, inorganic fertilizers have come into use, although in relatively small amounts apart from some special crops. Their influence in France, along with other improvements in crop husbandry, may be seen in the improvement in average wheat yields, which increased from 16 bushels per acre in 1869–80 to 23 bu. per acre in 1934–8 [20]. On the whole, soil fertility has been maintained at a rather low to moderate level around the Mediterranean; mean wheat yields in 1932–6 or 1929–38 were (bu. per acre): Greece 13, Spain 14, Italy 21, France 23. Exceptional is the fertile plain and delta of the Po where very high rice yields are obtained by manuring the alluvial soils (paddy rice, 93 bu. per acre).

Europe (north of the Mediterranean regions).—The methods of peasant farming in the Middle Ages were of a fairly uniform kind all across central and northern Europe, although social organization varied [21].

Traditional agriculture persists to-day in eastern Europe, and much the same system was used in England before the Inclosures began. Typical was the 'three-field system' of medieval England, where two fields were under grain crops and one field under weedy fallow, with some grazing. The stock-carrying capacity of the farms was not high; what stock there was (apart from pigs grazed in the forests) assisted to maintain soil fertility through their excreta, but these were not well conserved, and fertility was, in fact, at a low level, depending chiefly on natural recuperation. The crop yields of a number of farms in medieval England are well documented in ancient account books, and the average wheat yield was between 8 and 10 bu. per acre [22]. Low average yields similar to those of medieval England have been recorded recently from the peasant countries of eastern Europe; taking countries where little or no change has been made in traditional methods of soil-fertility maintenance we have (wheat yields in bu. per acre in 1928–37 or 1932–6): Russia 12, Rumania 12. Many Russian soils show the signs of severe nutrient deficiency and give large responses to fertilizers [23, 24, 25].

India.—The early valley-plain civilization of Mohenjo-Daro doubtless resembled other such civilizations in depending largely on river silt for fertility maintenance; the soils around the Mohenjo-Daro site are now very saline, and it seems possible that one reason for the decline of the civilization was the development of alkali soils. In the Vedic literature of several thousand years ago, manuring is referred to [26], but in present-day traditional Indian agriculture very little manuring is done, the two chief reasons being that cattle manure is mostly dried and used as fuel, and that there are religious and social objections to the use of human excreta. In a few localities in southern India, perhaps where alternative sources of fuel are available, cattle manure is systematically employed; but apart from this soil-fertility maintenance depends on natural recuperation, on silt from irrigation-water or erosion run-off, and on a limited amount of green manuring. Even in the great alluvial plains it is evident to the eye that most of the soils are seriously nutrient-deficient, whilst large responses have been obtained in fertilizer experiments [27, 28]; in upland situations the signs of soil-nutrient deficiency are still more obvious, being shown by the poverty and patchiness of the crops and the occurrence of strikingly better growth on the 'manure spots' left by labour animals.

In the drier parts of India soil-nutrient deficiency is less severe than in the humid areas, and moisture supply generally limits crop yields; yet even here, especially with irrigation, responses to fertilizers are observed. In fact, most of the soils of India have been starved and exhausted of plant-foods, and fertility maintenance in the past can hardly be said to have existed. Crop yields are low, in high-rainfall as well as low-rainfall areas; the average wheat yield in India (1935–40) was only 10 bu. per acre, and the average yield of paddy rice about 28 bu. per acre (equal to 14 bu. of milled rice).

China.—Chinese agriculture first began in the watershed of the Yellow River, as a valley-plain civilization; but in the course of time it spread outwards into the hilly regions and adopted techniques, such as

terracing, which made continuous agriculture possible here also. As far as reliable historical records go, systematic manuring was not adopted until fairly late in the development of traditional agriculture [29], at a period equivalent to Graeco-Roman times in Europe. For many centuries before the present time the methods of manuring described in Chinese agricultural literature [30] have resembled those of to-day: the most important source of plant-food, especially of readily available nitrogen, is night-soil; ashes, cattle and pig manure, composts, and green manures, as well as other local materials like oilseed cakes and crushed bones, are also employed.

This method of fertility maintenance, employed also until quite recent times in Japan, is widely known abroad, particularly from the eulogistic and charming account of F. H. King [31]. It is good as far as it goes, but its value appears sometimes to have been overrated, and its disadvantages overlooked. The fertility of Chinese soils is, on the whole, at a moderate rather than a high level; there is a closed cycle of plant-nutrients, in which no more can be added to the soil than is taken out of it, and there are inevitable losses which are barely balanced by natural recuperation. Thus so far as plant-nutrient supply is concerned, yields cannot be raised above the present level by the existing system alone. To improve crop production appreciably it will be necessary to bring more plant-nutrients into the cycle from outside sources.

A further and very grave disadvantage is the high death- and disease-rate from soil and water pollution due to the widespread use of night-soil. This aspect was neglected by F. H. King and his followers, but no one who has lived long in China can ignore it. Heiser remarked, after a lifetime of public health work in Asia, that 'water and soil pollution are the root causes of mortality in the tropics' [32], and this is undoubtedly the reason why China has the highest death-rate in the world (variously estimated at from 28 to 30 per 1,000 annually [33, 34]). Winfield has stated (in a lecture) that out of the total death-rate at least 8 per 1,000 are due to what he calls 'faecal-borne diseases', i.e. diseases carried by night-soil used as manure. Buck [33, p. 265] doubts whether China can justifiably continue to use night-soil, unless the process can be made sanitary, and there are immense practical difficulties in the way of doing this.

The most fertile soils of China are those of the alluvial plains, where fertility maintenance depends both on the silt from irrigation- or flood-waters, and on the high population density that has grown up in such areas. This, in China, results in a high level of manuring. The use of night-soil as manure, and the cost of transporting it for more than a limited distance, has led to the building up of a ring of highly fertile soils around the cities, with a corresponding degree of impoverishment of the country farther away [35]. These, the alluvial plains and especially the land near the cities, are the regions most commonly seen by short-term visitors to China (including F. H. King), but they represent only a small fraction—about one-fifth—of the area of agricultural China as a whole. In the hilly parts of China the fertility of the soil is generally lower than on the plains; crops are poorer, and the effects of nutrient deficiencies are evident to the eye [36].

This rather critical account of soil-fertility maintenance in China is given, not to belittle the achievements of Chinese farmers—for indeed they have maintained the fertility of their soils at a higher level than the practitioners of most other systems of traditional agriculture—but in the attempt to present a more balanced picture than that drawn by writers who have had little or no acquaintance with China as a whole. It is obvious to the discerning eye that most Chinese soils are nutrient-deficient; the same result has been shown by over 500 modern-type fertilizer experiments, which have given significant—and often very large—responses in over 80 per cent. of the experiments done. The nature and degree of the deficiencies vary in different regions and in different soils; on the whole, the leached soils of central and south China are more nutrient-deficient, and more responsive to fertilizers, than the unleached soils of the north [37]. The fact that the general fertility of Chinese soils is moderate rather than high is clearly shown in the average crop yields, which for most crops are lower than those achieved in intensive modern agriculture. The average yield of wheat, for example (1929–33), was 16 bu. per acre; and of paddy rice, 67 bu. per acre according to Buck's survey [33], or 53 bu. per acre in a more recent estimate by the National Agricultural Research Bureau.

(*c*) *Modern agriculture.*—This may be described as agriculture which makes use of recent technical and scientific improvements, including machinery, planned crop-rotations, and artificial fertilizers, as well as better crop varieties and pest- and disease-control. Not all of these may be utilized in one system of agriculture: indeed, modern agriculture may be divided into the two types, extensive and intensive, of which the former employs mechanization and improved varieties, but makes little use of rotations, fertilizers, or pest-control. Both these types of modern agriculture differ from traditional and primitive agriculture in the much greater productive ability of the labour employed, and the correspondingly greater wealth, and higher standard of living, of the rural population. There is also plantation agriculture, which includes some elements of both the extensive and the intensive systems. In the great extent of the areas devoted to a single crop it resembles extensive agriculture, but the mechanization of cultural and harvesting processes is difficult, and a large amount of handwork is involved, which necessitates a plentiful supply of cheap labour. Plantation crops require careful attention to cultivation, manuring, cover-cropping, and pest-control, as well as varietal improvement; in this their culture more resembles intensive agriculture than the extensive form.

Modern extensive agriculture.—The cultivation of large areas of land by a small number of people, using the highest possible degree of mechanization, was a dramatic event in world history which until a decade or two ago was generally applauded as the 'conquest' of previously unproductive parts of the earth's surface. The system is largely one of mono-cultures: wheat is grown in one region, maize in another, other crops elsewhere, with little or no rotation of crops; at most there is some fallowing to conserve moisture and suppress weeds. Fertility maintenance depends on utilizing soils with large reserves of fertility,

or on securing low yields over large areas, maintained at that low level by natural recuperation. The method is, in effect, one of mining the soil: by now it has led to soil exhaustion and to severe erosion by wind or water in many parts of the world, and the 'conquest' appears to be less complete than had been imagined. Presumably, like Indian or Russian peasant agriculture, the present system will be able to continue at a low yield-level for centuries, where conditions are favourable; but in marginal areas soil fertility is likely to be reduced so much that further cultivation will become unprofitable. Further, where rainfall is a limiting factor there is more danger of producing 'man-made deserts' under this than under any other agricultural system.

Indeed, such deserts are already present or extending in various parts of the world, and a depressing sight they are, whether seen from the air or from ground-level. The notorious 'dust-bowl' of the western central U.S.A., of which much was heard in the thirties, is an example of the dangers inherent in extensive agriculture; other such dust-bowls have developed in recent decades in Canada and Australia [38]. They have to some degree been brought under control by modified or restricted cropping operations, and by the complete prohibition of cultivation over large areas [39, 40]; a series of years moister than usual may help the recovery, just as a run of dry years precipitated the original trouble; constant vigilance will be necessary henceforth to ensure that dust-bowl conditions do not spread or recur.

The yields obtained under extensive agriculture are generally low, and surprisingly so when compared with those obtained under intensive agriculture—for example, with wheat (bu. per acre, 1928–37), average yields were: Australia 12, U.S.A. 13, Canada 13, Argentine 13. The yields in some parts of these countries were certainly limited by moisture-deficiency, but in other parts wheat is grown on soil initially very fertile, under optimum environmental conditions, and yet the average yields remain low. Undoubtedly many of the soils are suffering from severe nutrient-deficiency, as may be seen from inspection of the growth of crops in the field and from the responses to fertilizer experiments.

The United States of America has been included here as an example of extensive agriculture, which it is in respect of wheat (except in a few of the eastern States); but intensive modern agriculture also prevails, particularly in the eastern States and in irrigated areas of the west. Under extensive agriculture in the U.S.A. the average rates of fertilizer applications are small, and practically no organic manure is employed; under intensive agriculture considerable amounts of fertilizer are used—very heavy applications on some valuable economic crops [41]. Fertilizers are chiefly used in the humid eastern States, where nutrient deficiencies are greatest; here deficiency of phosphate more often limits crop production than does that of any other fertilizer [42]. Farmyard and other organic manures are also employed, although not to the extent in which they take part in soil-fertility maintenance in western Europe. Agricultural advisers in many parts of the U.S.A. are now advocating the greater use of organic, including green, manures [43]. Only one-sixth of the cropped area of the U.S.A. is fertilized each year, and

probably a still smaller proportion of the wheat area. It may be noted that a survey of farmers who used fertilizers on wheat, in the eastern States, showed that the average wheat yield without fertilizer was 13 bu. per acre; with fertilizer, 22 bu. per acre [41, p. 22].

In Australia phosphate-deficiency has for long been recognized as a limiting factor with wheat and other crops, and phosphatic manuring has been employed; in parts of south Australia, and possibly elsewhere, the stage has now been reached where nitrogen-deficiency is a more serious limiting factor than phosphate-deficiency, and there are considerable responses to nitrogen even under fairly low rainfall conditions (Prescott, private communication).

Modern intensive agriculture.—This, as carried out in England, Germany [44], and other countries of NW. Europe (and to a varying degree elsewhere), is characterized by the use of considerable amounts of inorganic fertilizers, in addition to farmyard manure or other local manures, and by the deliberate use of grazing animals and of grassland as a means of maintaining soil fertility. Some propagandists write as though the use of 'artificials' alone characterized modern intensive agriculture, but in Europe nothing could be farther from the truth, and lest this view should be accepted overseas it is necessary to stress aspects of modern agriculture that may seem familiar enough to those who already know the facts. Good farmers in the countries mentioned go to much trouble to raise livestock, and to utilize their excreta directly or via grazing, regarding them as 'manure-making machines' quite as much as a profit-making branch of farming. E. M. Crowther has pointed out [8, 45] that up to the war years English farmers imported more plant-nutrients in the form of feeding-stuffs for livestock than they purchased directly as fertilizers, and a large part of the plant-nutrients in the materials fed to the livestock eventually found their way on to the land. (For detailed surveys of the manuring actually employed by English farmers, see [46] and [47].)

The resultant system is one form or another of mixed farming, combining crop husbandry and animal husbandry on the same farm; more rarely, bulky manures are bought locally and carried to a purely arable farm. The intricacies of such systems are too many to discuss in a brief article, but the main outlines follow for the benefit of readers in countries where mixed farming is not pursued. Under the old, Norfolk, four-course rotation, sheep were folded on the turnip break, and this, along with any cattle- or horse-manure the farm produced, served to maintain soil fertility. Many farms had some fields that were permanently under arable cropping and others under permanent grass; the manure from cattle, grazed partly on the latter fields, and kept in yards or stalls in the winter, was used on the arable fields. In England the rigid four-course rotation is now less closely followed, and there has been a growing interest, led by Stapledon [48], in 'ley farming' or alternate husbandry, in which the same field may carry arable crops for several years and then be put down to a temporary ley, with mixed grass and legume as herbage, for several years more. The ley is either grazed directly or cut for hay and fed to animals whose manure goes on the land [8, 49, 50].

These or similar systems characterize the arable farming not only of England but of the Scandinavian countries and Germany and of New Zealand. They are incorporated to a varying degree in the agriculture, often more closely related to peasant farming, of France, Switzerland, and the central European countries; also in the agriculture of Pennsylvania and other eastern States of the U.S.A. Their effectiveness in maintaining soil fertility is seen in the high average yields obtained for the crops grown under such systems. Taking wheat, the average yields were (in bu. per acre, 1928–37 or 1932–6): Germany 32, Great Britain 33, Belgium 38, Denmark 44, Netherlands 45. For Scandinavia and Finland (1926–30 and 1935) 34, for New Zealand (1930–9), 31.

The contrast between these average yields and those recorded under other systems of agriculture is striking. It might be objected that conditions in NW. Europe are especially suited to wheat production, but this is not so: wheat is here far from its climatic optimum, and adverse seasons are frequent; soils are leached, sometimes actually podzolized; the medieval yields, as was shown earlier, were low. It must be attributed entirely to the success of modern, scientific, intensive agriculture that the wheat yields of NW. Europe have been raised from the medieval 10 bu. or so per acre to the present-day level of over 30; and a great part of this is due to the skilful maintenance of soil fertility resulting from mixed farming, with the use of both organic manures and inorganic fertilizers. In fact, it is not simply the maintenance of soil fertility that has here been achieved but its steady improvement. Even during the recent war years, by using more fertilizers on wheat under this system of agriculture, British farmers raised wheat yields from the already high level of 33 bu. per acre to an average (1939–43) of over 35 bu.

It might also be objected that mixed or ley farming is possible only under favourable climatic conditions, such as those of NW. Europe, but this is far from true, for some kind of mixed farming can be carried out under almost any climatic conditions, as the example of China shows. Ley farming is easier in the western European type of climate than in some others, but by the selection of suitable herbage or fodder species, ley or mixed farming can be conducted in most parts of the world, including the tropics [13, 51]. On the farm of the Roseworthy Agricultural College, South Australia, for example, under a highly seasonal rainfall of only 17 in. annually, wheat yields were increased by 50 per cent. in a few years by changing over from continuous wheat cultivation to ley farming. This was made possible by using species of grass and legumes suited to the climate [52]. With cotton-growing in Queensland, again, high yields have been obtained on rather infertile soils after dairy farming has led to the establishment of good temporary leys which, when ploughed up, suit cotton well.

Rice.—This crop, so widely grown as the swamp or paddy form in the warmer parts of the world, differs greatly from other crops in its soil requirements, yet the general principles of fertility maintenance remain the same. It is often grown on the alluvial plains of large rivers, where the soils are initially rich, with large reserves of fertility, so that high initial yields are secured. The crop is usually irrigated by muddy

irrigation-water, and the silt so added helps to maintain the fertility of these soils. Even if the irrigation-water comes from local sources rather than from rivers, it is often muddy through the erosion of hill-sides or sloping cultivated fields that lie above the paddy-fields, and the rice benefits. There is also some natural recuperation of fertility through nitrogen-fixation by soil micro-organisms (the conditions for this vary greatly under different types of rice culture, and they require much more investigation). However, the poor yields obtained from rice grown on leached soils, where most or all of the water used is rain-water, show that natural recuperation is a less important factor than silt from irrigation-water for fertility maintenance under continuous paddy cultivation.

Under discontinuous cropping, natural recuperation may play a greater part. This happens in Australia, where very high average rice yields (84 bu. of paddy rice per acre) are obtained under a system in which a single crop of rice, manured with sulphate of ammonia and mechanically cultivated, is grown after several years of fallow [53, 54].

Whatever type of natural fertility maintenance be present, paddy rice usually responds to manuring, with either local manures, inorganic fertilizers, or both. A response is the more likely because water-supply is not a limiting factor in the growth of the crop; and the response may be very great if no manuring is normally employed, on account of the leaching of the soil that tends to accompany paddy cultivation. The importance of manuring for rice may be seen by contrasting the average yields in countries where little or no manure is given (India 28, Ceylon 18 bu. per acre) with those in countries where local or inorganic manures or both are used (China 53, Japan 68, Italy 93 bu. per acre). These yields all refer to paddy rice (rice in the husk); for comparison with other crops, note that paddy rice loses about one-third of its weight, or one-half of its volume, when the husk is removed.

Plantation agriculture.—This refers chiefly to tropical and subtropical crops, grown on a large scale but receiving fairly intensive treatment. Until recently the attention paid to soil-fertility maintenance varied greatly with different crops and in different countries [55]; some crops depended largely on local manures, cattle being kept for the purpose of making manure; some, notably sugar-cane [56, 57], used large amounts of artificial fertilizers; and some merely mined the soil. Owing to the clean cultivation previously practised, the generally sloping character of plantation land, and the severe tropical rainfalls, soil erosion became widespread, and it formed a menace to the survival of many plantations [13, 58]. More recently, soil-conservation measures, including controlled weeding and cover-cropping, have been undertaken, whilst more attention is being given to the scientific maintenance of soil fertility not only by the use of cattle manures and inorganic fertilizers [e.g. 14, 59, 60], but by digging-under crop residues and green manures. Some composting is also done, but on the whole it has proved too expensive in labour and transport, and the turning under of green plant-materials has proved more effective [61].

Grassland farming.—For economy of space this discussion has been restricted to agriculture *per se*, although the importance of pastoral farm-

ing is not forgotten. Over quite large areas of the earth's surface, extensive grazing is the chief method of land-utilization, and this may maintain the fertility of the soil at about its natural level if too many head of stock are not carried. Over-heavy stocking, however, leads to impoverished herbage and accelerated erosion, with consequent loss of fertility, especially in dry regions. Serious wind or water erosion due to over-grazing now exists in many parts of the world, notably in the U.S.A., in Australia, in Africa (under the native tribes), and in India. Where this occurs, the possible benefit to soil fertility from the manure of the grazing animals is more than offset by the loss of soil due to erosion. The control of over-grazing, and the re-establishment of depleted grasslands, is one of the most urgent problems of world soil-fertility maintenance.

With modern, intensive, grassland farming, on the other hand, there has been a striking gain in soil fertility in many parts of the world. Over-grazing of pastures is avoided by providing fodder from other sources, if necessary, in order to carry the stock through the winter or through dry seasons. Then, by using artificial fertilizers and lime to make up any soil deficiencies, and by careful improvement and management of the herbage and the stocking, the carrying capacity of the pastures can be increased to a remarkable degree, and the fertility of the soils correspondingly raised. Striking examples of this are to be seen in New Zealand, where areas that were notorious a generation or two ago for the poverty of their soils and their livestock, are now famous for their richness. The Waikato district of the North Island is an example: here, by the use of lime and phosphates, with good seed-mixtures, large areas of swamp, bush, or poor pastures have been converted into high-class grazing land, with a carrying capacity multiplied many-fold. The effect of this in still further raising the fertility of the soil may be seen from Bruce Levy's estimate that the livestock on a high-class pasture in New Zealand return to the soil, in their excrements, nitrogen equivalent to 15 cwt. of sulphate of ammonia, and phosphate equivalent to $5\frac{1}{2}$ cwt. of superphosphate, per acre per year [62]. This improvement of soil fertility under good, permanent pasture is, of course, similar to what takes place under a well-managed temporary ley.

Discussion

Soil erosion and conservation.—These related subjects, referred to briefly when discussing systems of land-utilization, are a major factor in soil-fertility maintenance. The severity of erosion depends in the first place on the type of climate, which may make easy or difficult the conservation of the soil under any agricultural system. Erosion is worst in semi-arid areas, where rain falls in heavy showers when it does fall, where wind erosion is common, and where vegetation is easily destroyed and difficult to re-establish. It is bad also in extremely high-rainfall areas, where downpours of several inches of rain in a day are frequent, notably in the tropics. It is not negligible, however, even under the mild climatic conditions of Great Britain. Although it is much less serious or conspicuous here than overseas, being mostly in the form

of sheet erosion, it is still sufficient, for example, to produce thin soils, in which the subsoil is brought to the surface by ploughing, on moderate slopes. The severity of water erosion depends on the steepness of the relief, but wind erosion is serious also on level land, if the rainfall is low.

The control of erosion and the conservation of the soil are now receiving world-wide attention, though more effective action is still needed; and methods have been found, notably in the U.S.A., for minimizing this cause of soil-fertility loss under both extensive and intensive systems of modern agriculture. An immense literature has grown up on the subject; reference will be made here only to the comprehensive surveys by Jacks and Whyte [63] and by Bennett [64], and to a few recent publications [13, 36, 39, 65, 66, 67]. Erosion losses have always been severe under primitive and traditional systems of agriculture, at least in hilly countries; and they have been minimized under such systems only by abandoning the eroded land (as in shifting cultivation) or by careful terracing.

Relation of fertility to relief.—Given adequate drainage where it is needed, level land is on the whole more fertile than sloping land: a fact to be kept in mind when assessing the values of different regions or agricultural systems. This is the result, of course, of the transport of fertile top-soil from the hill-sides to the plains, by erosion and flood deposition; also of the better water-supply of the plains in semi-arid regions. One might say that under primitive or traditional agricultural methods alluvial plains are self-maintaining in fertility (except where buried in outwash from the hills), whereas hilly lands are self-destructive. This is very evident, to the perceptive eye, in China. Under modern agriculture, with soil-conservation practices, gentle slopes on hilly land can be cultivated without loss of fertility, but steeper slopes can maintain their fertility under cultivation only if terraced. Otherwise they should be kept under grass or forest, or under carefully managed tree (including plantation) crops with a complete ground-cover.

Relation between the fuel problem and soil-fertility maintenance.—This is particularly obvious in some of the eastern countries, where a long-continued, high population pressure has led to the destruction of most of the forests. Here deforestation and raking-up of forest litter by fuel-gatherers have accelerated erosion on steep slopes; and, in India, the use of dung for fuel has still further diminished the possibilities of soil-fertility maintenance. If dung is to be used as manure, then some other sufficient source of fuel or heat must be provided; if widespread afforestation is to succeed, the people must likewise be given fuel so that they will not damage the young forests. Improved transport, the exploitation of coal deposits, and, eventually, general rural electrification are thus essential factors in maintaining soil fertility.

Validity of generalizations.—In giving a condensed review of any complex subject one is forced to generalize; indeed, generalizations based on sufficient observations and data are one of the methods by which our limited minds can get to grips with the abundance of natural phenomena. It is inevitable in many fields that exceptions should occur, but they do not destroy the value of the generalization if the latter does, in fact, represent the general or the dominating conditions. The writer realizes

that many exceptions may be found to the general statements he has made in this brief review; but his conclusions are not hasty ones, and he believes that they fairly represent the dominating conditions under the agricultural systems reviewed.

Conclusions

Examining the maintenance of soil fertility under different systems of agriculture, we find that reliance is placed on three different methods, viz. (1) natural recuperation, supplemented by water-borne silt on alluvial plains, and including the 'mining' of the initial fertility of the soil where virgin soils are brought under cultivation; (2) the use of local manures, chiefly animal and other organic manures, ashes, and lime, to supplement natural recuperation; (3) the use of inorganic fertilizers to supplement local manures and natural recuperation. The first method maintains fertility at the lowest level; the second at a moderate level; and the third at the highest level. Indeed, it is only of the third that we can say that it has produced any marked increases in the fertility of infertile soils. The first method is exemplified in most primitive and traditional agriculture, including much peasant farming, and also in modern extensive agriculture; the second method is shown by the traditional agriculture of China and Japan, and the peasant farming of some European countries, especially those around the Mediterranean (where, however, inorganic fertilizers are increasingly coming into use as well); the third method is best seen in the modern intensive agriculture of NW. Europe, in New Zealand, and, for some crops, in the eastern United States. It is also employed in the most advanced forms of plantation agriculture. In some localities reliance is placed on the use of inorganic fertilizers alone, but under most systems of modern intensive agriculture organic manures also play a part, usually either farmyard manure, ley farming, or green manuring.

As an index to the fertility levels reached under the different methods of fertility maintenance, we may refer to the average yield of wheat. It is not pretended that this provides an absolute index to soil fertility, but the data obtained do give an objective measure which corroborates the conclusions derived from field observation; and the wheat crop is a widely grown one that receives good cultural treatment but not unusually heavy manuring. Average yields of wheat, in representative countries where one or other of the three methods predominates, were as follows[1] (bu. per acre):

Method 1. (Natural recuperation): India 10, Russia 12, Rumania 12, Australia 12, U.S.A. 13, Canada 13, Argentina 13, Egypt (fertilized by Nile silt) 25. For comparison, the wheat yield in medieval England was 8–10; and that on the continuously unmanured plot of Broadbalk experiment, before fallowing, 12. It seems that a wheat yield of around 12 bu. per acre represents the level at which soil fertility is maintained by natural recuperation without manuring, under a wide range of climatic conditions.

Method 2. (Natural recuperation plus local manures): China 16,

[1] Data are chiefly from International Institute of Agriculture publications, from official sources, or from references given in the text.

France (1869–80) 16. Other countries depending mainly on this method, as in peasant farming, plus a certain amount of inorganic fertilizer: Greece 13, Spain 14, Italy 21, France 23, Japan 25.

Method 3. (Natural recuperation plus local manures or temporary leys plus inorganic fertilizers): New Zealand 31, Germany 32, Great Britain 33, Scandinavia (and Finland) 34, Belgium 38, Denmark 44, Netherlands 45.

It seems therefore that 35 bu. of wheat per acre (which was also the average yield in England during the recent war years) represents in round figures the level of soil fertility that can be maintained under method 3, and that around 20 bu. per acre could be expected under method 2. Whatever actual figures be taken, it is clear that modern intensive agriculture, using both inorganic and organic manures, has achieved a marked advance in soil-fertility maintenance over the other systems, in which only organic manures, or no manures at all, are used.

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THE CULTIVATION OF THE TUNG TREE IN NYASALAND

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Introduction.—The two species of trees which produce tung oil, *Aleurites fordii* and *A. montana*, were introduced into Nyasaland in 1927 and 1931 respectively. The cultivation of the crop in the protectorate is therefore quite a recent development and is still to some extent in the experimental stage. The results obtained from the earliest trial plots led many European planters to establish small plantations of *A. fordii*, but although these trees made good vegetative growth in many localities their yields were poor, and *A. montana* was subsequently found to be much more promising. An attempt was made to improve the yield of *A. fordii* by making a survey of some of the oldest plantations, selecting the best trees and propagating them both as seedlings and buddings, but results from these trials have been disappointing, particularly as regards the performance of the buddings, which have shown little or no improvement over seedlings. Similar poor results from the vegetative propagation of selected *A. fordii* trees have been reported from South Africa [1], and it seems evident that there is little hope of raising the yield of this species to a level comparable with that of *A. montana*. The marked superiority of the latter species has resulted in its being planted almost exclusively since 1936, and for this reason no further reference will be made to *A. fordii*. Since 1936 the total area under tung trees in the protectorate has increased from 624 acres to 8,349 acres at the end of 1944 [2, 3]. The whole of this acreage is on European estates at elevations of 2,500 to 4,000 ft., in districts where the rainfall is not less than 40 in. per annum and where there is a cool dry season from May to August, when the trees shed their leaves and become dormant.

As can be seen from the figures just quoted, the expansion of tung planting has not been rapid and the total area under the crop is still relatively small. It should also be noted that the cultivation of *A. montana* as a plantation crop is an almost equally recent development in other parts of the world, and it has therefore been impossible to draw on plantation experience or the results of experimental work from other countries, particularly as the territories in which the crop had made most headway (Burma, Indo-China, and the Dutch East Indies) were cut off by the Japanese occupation in 1942. Experimental work in Nyasaland was begun with the opening of the Tung Experimental Station at the end of 1940, and it will therefore be realized that only a small beginning has yet been made with some of the more immediate problems connected with the crop.

Nature of seedling plantations.—In the early years all plantations were established from seed to which no form of selection had been applied, and the first experiments with buddings were not begun until 1940. The variation in flowering habit and yield which is found in a seedling

plantation of *A. montana* has already been described in some detail elsewhere [5, 6]. Briefly, although the species is monoecious, it is found that some 40 to 50 per cent. of the trees are very predominantly male and therefore bear only a few clusters of fruit, whilst the remainder, known as 'bearers', produce a much higher proportion of female flowers and consequently set much more fruit. These facts are illustrated by Table 1, which shows the average yields per tree of a seedling plantation of 123 trees at Zomba from 3 years old, when they began to fruit, until the tenth year. (In this paper all yields are expressed as lb. of dry seed, by which is meant the seed removed from the fruit and air-dried. This seed yields approximately 33 per cent. of oil on crushing in the factory.) In this plot 48 trees are male and the remaining 75 are bearers. The first line of figures gives a very fair indication of what may be expected from a plantation of unselected seedling trees on average soil and given reasonable, but not intensive, cultivation. It will be seen that the yields increased steadily up to the tenth year. It is not yet known at what age full bearing is reached, nor have we any reliable information as to the fruitful life of the tree, but I have seen semi-wild trees in Burma which were at least 35 years old and were still bearing well. The yield of the Zomba trees at 10 years old is equivalent to 1,148 lb. of dry seed per acre at the 30-ft. hexagonal spacing of this plot. The low yields of the male trees can be seen from the second line of figures. The majority of the bearing trees have given only moderate yields, but a few are outstandingly good, and this variation is shown by a comparison of the figures in lines 3 and 4 of Table 1, and also by Table 2.

TABLE 1. *Average Yields of 123 Seedling Trees of* A. montana *(lb. of dry seed per tree)*

Age, years:	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. All trees	1·7	3·6	5·2	9·4	11·8	13·7	15·1	20·5
2. 48 male trees	0·1	1·0	0·5	1·2	2·0	2·3	2·7	5·2
3. 75 bearing trees	2·7	5·9	8·2	14·6	18·1	21·1	23·1	30·4
4. 12 best bearers	4·8	8·7	17·1	27·5	28·4	35·3	33·2	50·8

TABLE 2. *Frequency Distribution of 75 Bearing Trees according to Yield in Tenth Year*

Yield class, lb. dry seed	*0–10*	*10·1–20*	*20·1–30*	*30·1–40*	*40·1–50*	*50·1–60*	*60·1–70*	*70·1–80*
No. of trees	4	12	27	15	8	6	2	1

Production of Improved Planting Material

It is immediately evident that the vegetative propagation of the best bearing trees selected from seedling plantations offers great possibilities of improving yields per acre, since by this means the males would be entirely eliminated and the plantation would consist of clonal material derived only from the outstandingly good bearers. Selection of good mother trees was begun in 1940 by examining plantations tree by tree,

picking out exceptional individuals, and recording their yields for several years. Yield is regarded as the most important criterion, but other factors such as vigour, habit, and the percentage of seed, kernel, and oil in the fruit are also receiving consideration. So far 662 provisional selections have been made from a survey of just over 40,000 trees. The work has been handicapped by the absence of any great number of older trees in Nyasaland, and by the fact that in working with young plantations there is a tendency to select for precocity. It will be necessary annually to re-examine the plantations for a considerable period, and it will probably be found that many of the trees now bearing most heavily in these young plantations will subsequently be surpassed by slower maturing trees. A number of outstanding trees have, however, already been found, including several which have given over 75 lb. of dry seed in a single season.

In early experiments on vegetative propagation little success attended attempts to root cuttings, stools, or layers, but budding on to seedling root-stocks was found to be a simple matter, and the resulting budded plants were easy to handle and transplant [7, 8]. Budding on to seedling stocks has therefore been the method of propagation so far adopted. After several years of yield-recording the most promising of the selections are being planted out as buddings in clone tests in order that final selection may be based on the performance of the buddings rather than on that of the mother trees. At present 68 clones are under trial at the station, but less than half of these are yet in bearing, and in this paper reference is made only to the 12 oldest clones planted at the end of 1940, most of which are derived from the Zomba trees from which yield-records have been kept since they began to fruit.

A direct comparison between buddings and seedlings is made in a trial planted in 1940 in which the treatments are: (1) unselected seedlings derived from ordinary bulk seed, (2) 'selected seedlings' raised from open pollinated seed taken from 4 selected trees, (3) and (4) buddings from the same 4 selections on *A. montana* and *A. fordii* stocks. Owing to the rather poor soil on which this trial is sited the yields (Table 3) have been rather low, but it will be seen that buddings on *A. montana* stock have significantly outyielded both types of seedlings, giving nearly three times as much as the unselected seedlings. Both types of seedlings have made appreciably stronger growth, as indicated by girth measurements, than the buddings, the difference in vigour now being quite obvious to the observer in the field. The *A. fordii* stock is clearly exerting a dwarfing effect, and its yield fell below that of the buddings on the *A. montana* stock in the fourth year, and is expected to continue to do so. Seedlings of the candlenut tree (*A. moluccana*) have also been tried as a stock for both *A. montana* and *A. fordii*, but the species appear to be incompatible. In a second experiment, also planted in 1940, a comparison of 5 clones and 4 cultural treatments is effected, and the yields obtained from the best cultural treatment (intercropping with soya beans, which are harvested) are shown in Table 4. Further yields from a number of small plots on an estate are shown in Table 5. Yields from these latter clones are not strictly comparable as they come from single plots on several

different fields, but they give some indication of what may be expected from young buddings under average conditions.

TABLE 3. *Mean Yields from Buddings and Seedlings (lb. dry seed)*

Age, years		*Buddings*		*Seedlings*		*Significant differences*	
		Montana stock	*Fordii stock*	*Selected*	*Unselected*	$P = 0.05$	$P = 0.01$
2	per tree	0·27	0·29	0·02	0·02	..	..
3	per tree	1·85	1·69	0·89	0·69	0·36	0·50
	per acre	104	95	50	39	..	..
4	per tree	6·72	3·70	3·06	2·35	1·41	1·95
	per acre	376	207	171	132	..	..

TABLE 4. *Mean Yields of Clones (lb. dry seed)*

Age, years		*Clones*				
		ZN24	*ZM8*	*14*	*ZF9*	*10*
2	per tree	1·03	0·43	2·37	0·77	3·07
	per acre	58	24	133	43	172
3	per tree	3·40	2·22	7·72	3·65	7·57
	per acre	190	124	432	204	424
4	per tree	9·15	6·62	13·85	7·55	13·33
	per acre	512	371	776	423	746

TABLE 5. *Mean Yields per Tree of Clones from Single Plots (lb. dry seed)*

Clone:	*ZL22*	*ZO23*	*14*	*14*	*ZH14*	*ZM8*	*ZK3*	*10*	*ZO8*	*ZM13*
No. of trees	*20*	*19*	*20*	*83*	*10*	*19*	*13*	*20*	*9*	*12*
2 years	4·0	5·1	7·8	..	2·9	2·4	2·8	4·5	8·6	9·6
3 years	2·9	4·0	4·6	..	2·2	2·4	5·8	1·3	7·8	4·1
4 years	10·3	11·6	16·0	22·5	14·3	12·4	22·4	12·4	14·6	21·5

Although records are as yet only available from a few young clones, the yields obtained are promising and it seems very unlikely that buddings will fail to produce a considerable improvement over seedlings. Seven clones have given from 12 to 22 lb. dry seed per tree in their fourth year, or from 3 to 6 times as much as a good seedling plantation yielded at the same age (cf. Table 1). Better yields than those given above are expected in the near future, as amongst the more recently selected mother trees there are some that are proving superior to those from which most of the older clones are derived. It is also hoped that further improvement will result from work begun in 1942 on the artificial crossing and selfing of selected trees with the object of producing a number of legitimate seedling families from which it is hoped later to produce improved planting material by vegetative propagation from the best individuals. The question of improvement of root-stocks is also being investigated; further attempts are being made to root clonal

material as cuttings, &c., and trials are being made with seedling stocks raised from seed produced by the artificial selfing of selected trees.

It may be mentioned that although all budding has hitherto been done on seedling stocks, certain characteristics of the mother trees are reproduced with remarkable uniformity in all the buddings derived from them, and there are marked differences between clones in vigour, habit, time, and type of flowering, &c. Of particular interest is the fact that the majority of clones fall into two distinct classes as regards habit of growth. Type A clones make vigorous trees which increase rapidly in height, making whorl after whorl of primary branches one above the other on the main trunk, and producing secondaries only at relatively long intervals. Type B is less vigorous, branches low and produces secondaries at short intervals, and tends to make low, dense, bushy trees. The latter type produces far more potential fruiting points in the early years and is usually more precocious in bearing. Further reference to these two types of tree is made under the heading of spacing.

In the older seedling plantations the topworking of the male trees by budding on to the main branches with scion buds from high-yielding mother trees has been found to be a successful means of converting these trees into good bearers [9].

Cultural Methods

In discussing the cultural methods at present employed on tung plantations in Nyasaland it must be emphasized that these have not yet become standardized as a result of experience and investigation but are constantly being modified in the light of new information.

Nursery work.—The common practice is to sow the seed in the nursery as soon as possible after it is harvested in May, to bud the resulting seedlings about 16 to 18 months later, shortly before the rainy season (November to April) of the following year, and to transplant as budded stumps as soon as the rains have begun. A series of experiments has shown that when seed is sown in May, which is at the beginning of the cool winter season, the rather low soil temperature tends to reduce the speed of germination, and it is therefore best to keep conditions as warm as possible by sowing the seed shallow (1 in. deep) in open nursery beds without shade or mulch, and to avoid overwatering: 2 galls. per sq. yard on alternate days has been found adequate, and superior to daily watering. If the seed were stored for several months after harvesting and then sown in September–October, when the higher temperatures give more rapid germination and growth, they would still be big enough for budding a year later, and time and labour in the nursery would be correspondingly reduced. The difficulty, however, is that whereas fresh seed will give a germination of 80 to 95 per cent., its viability is much reduced by 3 or 4 months storage, after which only 40 or 50 per cent. of the seeds will germinate. A number of experiments were made to find some means of storing seed without loss of viability, and recently good results were obtained by stratification in moist sand and sawdust. This method, which had previously been tried with seed of *A. fordii* [10], gave a germination of 80 per cent. after 4 months, as compared with

50 per cent. from normal storage [11]. Further experiments on stratification are now in hand, and at the same time trials are being made with seed taken from the trees before the fruits are ripe and sown in March and April. It has been found that the latter seeds germinate readily, and it is hoped that the resulting plants may be big enough to bud by the following October, which would reduce the time in the nursery by nearly a year.

Transplanting.—The seedlings are budded by the modified Forkert method when they have reached a diameter of not less than $\frac{3}{4}$ in. at 6 in. above ground-level. The common practice is to bud in the nursery and transplant soon afterwards, cutting the main stem 4 in. above the dormant-bud patch, and pruning back the roots. Budding is also not infrequently done in the field on seedlings a year old which have been planted out 2 or 3 months after germination of the seed.

Spacing.—The majority of the early-seedling plantations were planted at a spacing of 30 ft. either on the square or the hexagonal system. Although no investigation of the root-system of the trees has been made, observations on the spread of the branches and the general appearance of the trees indicate fairly clearly that the ground is not fully occupied in plantations at this spacing until they are 10 or 12 years old, and suggest that for the first 7 or 8 years a greater density per acre is desirable. None of the plantations of budded trees is yet old enough to provide much information on the question of spacing, but the optimum planting distance will clearly vary with the clones used. It will probably be found best to use a mixture of the two types of clone previously mentioned in this paper, planting the type-A trees at a relatively wide spacing and interplanting with the quicker cropping and smaller type-B trees, which can be cut out in due course as the type-A trees mature and the land becomes crowded. Experiments to test this method of planting are already in hand.

Cultivation.—Early attempts to grow tung trees with no more cultivation than an occasional hoeing or slashing of the grass and weeds resulted in poor growth, thin yellowish foliage, and low yields, showing quite clearly that the trees cannot compete with the heavy cover of grass which grows during the rainy season. It has therefore become a common practice to intercrop with soya beans, tobacco, or native food-gardens consisting usually of a mixture of maize and beans. The only field experiment on intercropping yet in bearing is one planted with buddings in 1940 which compares intercropping for the first 4 seasons with (1) soya beans, (2) maize, (3) a green manure crop of *Mucuna utilis* dug in annually, (4) a cover crop of *Calapogonium mucunoides* intended to be permanent but which died out early in the fourth season owing to failure to set seed. No definite conclusions can yet be drawn from this trial, but results so far show a consistent superiority of the soya-bean plots both as regards yield and vigour, thus indicating the advantage of thorough cultivation with a crop which does not take much from the soil. With a permanent tree crop under tropical conditions the maintenance of soil fertility and structure should obviously be a primary consideration, and it seems doubtful if this can be achieved under any

system involving continuous intercultivation with annual crops. Trials are therefore being made in which for the first 2 years only a circle of 10 to 15 ft. diameter around the young trees is clean cultivated, the remainder of the land being left under grass, which is slashed at the end of the rains; for the next 2 years intercropping with annuals is practised to permit strong growth of the trees; and subsequently the plantation is put under a perennial cover-crop. Some cover crops are at present under trial, of which the most promising are *Glycine javanica*, *Pueraria thunbergiana*, and *P. javanica*.

Manuring.—No information on manuring is yet available beyond the fact that young trees, as might be expected, show a marked response in growth to quite small applications of nitrogen, and an indication that dressings of farmyard manure or good compost are beneficial to older trees on most soils.

Pollination.—In the early part of the flowering season the bearing trees usually open only female flowers, and male blossom is mostly produced when the bulk of the female blossom is over. The male trees, which have a longer flowering season than the bearers, open their few clusters of female flowers only after their main flush of male blossoms. It therefore follows that the female flowers on bearing trees are mainly cross-pollinated with pollen from male flowers on other bearing or male trees. A series of observations on flowering and pollination in budded plantations [4, 6] has shown that some clones produce no pollen at all during the early part of their flowering season, although during this period an abundance of female blossom is opened, whilst in other clones the amount of male flower open at any time is so small that it could hardly be adequate for proper pollination. The inclusion of a small proportion of early flowering male trees in a budded plantation is therefore desirable, and at present not less than 5 per cent. of males is suggested, although later work may show that a smaller proportion is adequate.

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RELATIVE INFLUENCE OF HEREDITY AND ENVIRONMENT ON FERTILITY AND HATCHABILITY IN WYANDOTTES

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In an analysis of records of official pedigree-breeding stations in Lancashire and Northern Ireland, Hutt [1] presents data showing that under the conditions obtaining in these locations, White Wyandotte eggs hatch much poorer than White Leghorns or Rhode Island Reds. This supports popular opinion, which regards the White Wyandotte as a breed characterized by low fertility and hatchability. Hutt attributes the subnormal reproduction-rate in White Wyandottes to the pleiotropic action of some gene or genes determining the characteristics of the breed, or to linkage of deleterious genes with those making the breed.

Although we have no critical evidence supporting Hutt's data concerning the inferiority of White Wyandottes as breeders, we do have evidence which shows quite conclusively that under certain environmental conditions White Wyandottes will give excellent hatchability. Unfortunately we cannot define or describe the necessary conditions, but we would like to place on record the excellent results secured at one of our Wyandotte farms, and show by controlled experimentation that this excellence was purely a matter of environment and not breeding.

Preliminary Data

Since 1923 we have complete hatching and brooding records on over 20 farms scattered throughout Canada from the Atlantic to the Pacific. With one or two exceptions each of these farms maintains only one breed and with one or two exceptions there has been no changing of breeds. Barred Plymouth Rocks are kept at about 16 farms, White Leghorns at 2, Rhode Island Reds were maintained for a time at 1 farm, and White Wyandottes were maintained at 3 farms until 1941. Since then one of these Wyandotte farms ceased to keep poultry, and Leghorns were substituted for Wyandottes at a second. These two farms were both located in British Columbia; one at Summerland in the Okanogan Valley and the other at Saanichton on Vancouver Island. The third Wyandotte farm, still in operation, is at Lacombe, Alberta.

The Summerland farm gave outstanding results particularly in incubation and brooding operations, and was apparently a very marked exception to the experience of practical breeders and to the contentions of Hutt [1] concerning the poor reproductive rate in Wyandottes. In the 17 years from 1924 to 1940 inclusive this farm was below the average of all farms only 5 times in fertility, once in percentage total of eggs hatched, and once in percentage of chicks alive at 3 weeks of age. In percentage of fertile eggs hatched it always exceeded the average. In the last 4 years of its existence this farm gave particularly good results, leading all others and being from 20 to 30 per cent. higher in hatchability than the

average. The Saanichton farm was also better than average, particularly in percentage of fertile eggs hatching. Its weakness was in percentage fertility, which generally ran in the 70's as compared with 80's and 90's for Summerland. Lacombe, on the other hand, has given consistently poor results, being generally below average in both fertility and hatchability. Table 1 summarizes the hatchability for these three Wyandotte farms for the 10-year period 1931–40.

TABLE 1. *Percentage of Total Eggs Hatched at Three Wyandotte Farms for the ten-year Period 1931–40*

Year . .	*1931*	*1932*	*1933*	*1934*	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*	*Average*
Summerland	56	61	53	61	64	60	75	87	80	83	68·0
Saanichton .	56	60	55	60	57	62	55	61	58	62	58·6
Lacombe .	30	54	50	46	37	39	43	50	50	49	44·8

As can be seen, there was relatively little difference between Summerland and Saanichton up to 1937 in percentage of total eggs hatching. However, Summerland was usually superior to Saanichton in livability during the early brooding period. When the incubation and brooding results are combined and expressed as the number of eggs required to produce one live chick at 3 weeks of age, and all farms (average number 21) are arranged in order of merit within each year, the standing of the three Wyandotte farms is that shown in Table 2.

TABLE 2. *Relative Standing of the Three Wyandotte Farms among a Total of 21. The other 18 Farms included both White Leghorns and Barred Rocks*

Year .	*1931*	*1932*	*1933*	*1934*	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*	*Average rating*
Summerland	8	1	8	2	1	4	1	1	1	1	2·8
Saanichton .	5	6	10	6	5	3	11	10	13	12	8·1
Lacombe .	19	11	13	14	18	19	17	17	17	18	16·3

In this table Summerland is generally superior to Saanichton and actually ranks first out of more than 20 farms during 6 of the 10 years. During the last 4 years, as shown in Table 1, Summerland was consistently from 20 to 30 per cent. higher than Saanichton, which in turn generally equalled or exceeded the average of all farms.

In considering the cause of the phenomenal results secured at Summerland one would naturally suspect heredity. All our farms have been carrying on pedigree breeding-work, and among other things all have been attempting to select for high hatchability. It would be logical to suppose that Summerland had been more successful in this respect than the others. However, several things militated against this explanation, chief among them being the fact that although inbreeding has been repeatedly shown to affect adversely hatchability, and though there is considerable evidence for the existence of hatchability differences between breeds, there has been no clear-cut demonstration that within a

breed the level of hatchability can be improved appreciably by selection. Also, there had been exchanges of stock between the various Wyandotte farms so that a degree of relationship existed between the flocks.

Experimental

In order to prove definitely whether heredity or environment was responsible for Summerland's results an exchange of pullets was undertaken in the fall of 1940 between Lacombe, with consistently poor hatchability, and Summerland, with consistently high hatchability, the average difference in hatchability between these two farms the last 4 years being 33·4 per cent.

The exchange was arranged early in the fall of 1940 just previous to sexual maturity. At each farm 56 pullets were selected at random and 28 of these interchanged. The experimental birds, therefore, consisted, at each farm, of 56 birds, 28 representing the home flock and 28 the co-operating farm. These birds were placed in 4 pens of 14 birds, each pen consisting of 7 birds from each of the two strains.

The birds were maintained in this manner through the winter, and in the spring a cockerel from the home strain was placed in each pen. The use of the home-strain males in all pens is open to the criticism that strain-crossing might result in better hatchability from the birds of outside origin, but if this is so, outside birds should give better results at both farms and thus balance the experiment. Four settings were made at each farm during the months of March and April and individual hatchability records were kept. The settings were spaced at weekly intervals at Summerland and at intervals varying from 8 to 18 days at Lacombe. The strains of course are strictly comparable within pens and settings at each location.

Analysis of Experimental Data

The data have been calculated and summarized in two ways, (1) by giving each egg equal weight, and (2) by giving each hen equal weight. In the first case the mean for each strain is based on all eggs laid within the pen and the hatch irrespective of the hen producing them. In this method the heavy laying hens have more weight in the results. In the second case the mean hatachability is calculated for each hen independently and the mean for the pen and the hatch is the average of the individual hens. By this method all hens have equal weight in the comparison irrespective of the number of eggs they produce.

In both methods the data have been calculated for each pen and each hatch separately and pooled by averaging the 4 hatches for each strain in each pen. These pooled data are shown by pens and according to both methods in Table 3. It can be seen that there was no difference between the two strains at Summerland, but at Lacombe the Summerland birds were more than 25 per cent. higher in fertility and an average of 10 per cent. higher in fertile-egg hatching. These results, secured in 1941, indicated that the two strains did not differ fundamentally, since at Summerland they gave similar results. The cause of the superiority of the Summerland birds at Lacombe was evidently to be sought in some

factor connected with moving the birds. In searching for this it was learned that the Summerland birds moulted after their arrival at Lacombe and were out of production for some weeks, whereas the amount of moulting in the Lacombe birds in the same pens was considerably less. This resulted in the Lacombe birds producing at a

TABLE 3. *Summarized Data collected in 1941, giving (1) each Egg Equal Weight, (2) each Hen Equal Weight*

	Summerland females				*Lacombe females*			
	Per cent. fertile		*Per cent. fertile hatch*		*Per cent. fertile*		*Per cent. fertile hatch*	
Pen	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Data collected at Summerland								
7	64·1	66·3	85·8	86·3	79·9	82·9	90·5	89·0
8	83·8	83·8	82·1	84·7	86·4	86·5	89·7	89·7
9	90·9	93·2	95·8	94·0	69·3	67·2	91·3	93·3
10	70·6	73·3	94·7	94·8	86·8	86·4	89·8	90·0
	77·3	79·2	89·6	90·0	80·6	80·8	90·3	90·0
Data collected at Lacombe								
A	85·1	85·4	80·2	81·1	43·2	40·2	58·1	61·8
B	56·8	58·3	73·7	66·0	58·8	56·9	62·1	66·2
C	76·2	70·9	80·1	78·6	44·6	48·2	52·3	57·1
D	95·3	95·0	79·6	75·8	59·2	62·7	84·9	87·7
	78·3	77·4	78·4	75·4	51·5	52·0	64·4	68·2

higher rate before the hatching season. A survey of the rations fed indicated that the amount of vitamin B_2 supplied was somewhat below optimum: an estimated 200 units per 100 gm. of feed as compared with a requirement of 230 units for hatchability. It seemed logical therefore that the heavier-laying Lacombe birds had depleted themselves of essential stores of this nutrient and possibly others as well, and were not at the same physiological level as the Summerland birds during the hatching season. Accordingly, all birds in the experiment at Lacombe were maintained for a year and further comparisons on fertility and hatchability secured in 1942. Furthermore, before the 1942 hatching season, the vitamin-B_2 content of the ration was raised to the required level by increasing the quantity of milk powder and by reducing the proportion of scratch grain fed. The results secured under these conditions are shown in Table 4.

TABLE 4. *Data collected in 1942 at Lacombe. Same Birds as in 1941 at the same Location. Pens and Hatches grouped together. Each Egg given Equal Weight*

Summerland females		*Lacombe females*	
Per cent. fertile	*Per cent. fertile hatch*	*Per cent. fertile*	*Per cent. fertile hatch*
98·1	72·4	98·9	71·4

Not only are the hatchability results considerably improved over 1941, but it is shown conclusively that the two strains do not differ when the environmental conditions are equalized.

Relation of Fertility and Hatchability

One of the most interesting conclusions to emerge from this study is that of the relationship between fertility and hatchability and its fundamental cause. Though much of the evidence is contradictory there does seem to be, on the average, a positive relationship between the two. The general experience of the breeder and hatcheryman is that when fertility is low, especially in flock-mated pens, hatchability of fertile eggs is also low. In an earlier publication the author suggested that this could be explained by assuming variations within the egg which influenced impregnation as well as embryonic development [2]. In other words, the low fertility may not be the fault of the male or of the sperm, but the egg may be either (*a*) infertilizable, or (*b*) incapable of supporting the zygote to the stage where fertility can be detected.

Such a theory can be proved only by detailed cytological and histological evidence. Very strong indirect evidence in its support exists, however, in the data presented in Table 3. At Lacombe the average fertility of the Summerland birds in the 4 pens is 78·3 per cent., whilst the Lacombe birds in the same 4 pens average only 51·5 per cent. fertile. It can be seen that 3 of the 4 pens show very large differences (average of 35 per cent.) in fertility between the two stocks, whilst the fourth, pen B, shows approximate equality.

There were 7 females of each strain in each pen, and since these birds were similar in size, colour, shape, &c., and since they had been mingling freely within the pens for several months before the hatching season, and since the males were placed in the pens just before the breeding season long after the females had established their social order, there seems to be absolutely no basis for preferential mating. Although preferential mating within each pen undoubtedly occurred, it would be quite impossible for the males in each of the 3 pens by chance alone to mate more frequently with the 7 Summerland birds than with the 7 Lacombe birds. Any preferential mating occurring should cut equally across the two strains.

There appear to be only two possible explanations for the large difference in fertility. First, preferential mating on the part of each of the 3 males, or second, poor internal egg-quality rendering the eggs infertilizable or causing very early embryonic death resembling infertility. It must not be overlooked that the second condition, i.e. infertilizable eggs or very early embryonic death, might also be caused by some environmental factor within the oviduct, such as a high body-temperature, which kills the highly heat-sensitive sperm before fertilization or the embryo in early cleavage stages.

This explanation of low fertility associated with low hatchability warrants further investigation and is now under study at this laboratory.

Summary

Although it seems to be well established that White Wyandottes on the average are poor in fertility and hatchability, the data presented in this paper show that under certain conditions, the exact nature of which is obscure, this breed will give excellent reproductive results. It is further evident that excellent and sustained records of high hatchability on the part of a flock or a strain at any one poultry-plant cannot be regarded *per se* as proof of genetic superiority in reproductive ability. It likewise follows that the converse, i.e. continued poor hatchability on the part of a flock at a single location cannot be regarded as genetic inferiority without further evidence.

One of the most interesting points to emerge from this study is the suggestion that low fertility may not actually be the fault of the male or of the sperm, but may sometimes result from infertilizable eggs, or from very early death of the embryo either before oviposition or while the eggs are being held for incubation, so that the incubated egg appears infertile on candling or when broken out for examination.

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WHEAT IN THE MIDDLE EAST

H. H. MANN

DURING the last four or five years the Middle East has attracted attention, not only for its political importance, but also for its potential value as a source of food supply for the external world. By the Middle East is meant the countries which lie round the eastern end of the Mediterranean and extend farther east to the confines of India. On the north the boundary of our area is the southern coast of the Black Sea, and on the south the mountains of Abyssinia. Within these limits it is probable that agriculture first developed, and wild grasses were first cultivated to give crops of cereal grains. It was here that, probably about 15000 to 10000 B.C. [1], the earliest wheat crop was reaped, and during almost the whole of the classical period parts of the Middle East were looked upon as the granaries of some at least of the political units of the west. Now, however, the situation is vastly different. Hardly any of the countries are much more than self-sufficient in bread grains (though several are exporters of barley), and they make very little contribution to the world's supply of its staple human foods.

Varieties.—All authorities agree that wheat originated in the area we are considering. In the ancient world Diodorus Siculus tells us that wheat was discovered by the goddess Isis in the country of Nysa, a high mountain in Phoenicia. Aaronsohn [2] claims that he has found a form of wild wheat on the hill-sides of northern Palestine. The earliest type of wheat grown seems certainly to have been emmer (*Triticum dicoccum*) or some progenitor of this variety. It is still grown by backward peoples in many parts of Europe and most parts of Western Asia as well as in Abyssinia. In south India, under the name of *khapli* wheat, it is quite extensively cultivated, largely because it is fairly resistant to diseases, notably to rust; but its cultivation is tending to contract and it will probably soon have little more than historical interest.

In later times, including the classical period, emmer was gradually replaced by two or three other types which still form the main wheat production in the Middle East. One of these, *Triticum vulgare*, common or soft wheat, which according to Vavilov [3] probably originated in the valleys of northern Iran (Khorassan), Afghanistan, or northern India, forms the basis of by far the greater part of the wheats cultivated at present in the world. They do not appear to be really adapted to a Mediterranean climate and have by no means so completely dominated the wheat position here as they have done in most of the temperate regions. They are, however, the natural wheats of the north of Iraq and the eastern regions of our area where the climate largely depends on the monsoon. Here, also, *Triticum compactum*, or club wheat, is largely grown.

The typical wheat of the Mediterranean region, and of all areas where the climate is similar, is *Triticum durum* or hard wheat. It appears to be the main wheat of cultivation in North Africa including Abyssinia,

in Asia Minor, and in the countries adjoining these centres. It is not very susceptible to the more common forms of rust, which is, as we shall see later, a very important matter in the Middle East. Hard wheat is essentially a crop of semi-arid climates and will stand a good deal of salt in the soil. In Iran and Iraq it is at least equally important with soft wheat, and it forms by far the most common variety in Egypt. In Syria and Palestine it is almost the only variety grown. It is taller than soft wheat and is always bearded. It is said [4] that the root-system is more extensive than that of *T. vulgare*.

In fact, in the Middle East, the present evidence seems to indicate that, whilst in Iraq and to the east of it, where, however indirectly, the influence of the monsoon prevails, the cultivation of *T. vulgare* does and should tend to be the most important, there is little doubt that in the remainder of our area the future lies with some form of *T. durum*. Unfortunately, except in America, until very recently little work was done in breeding improved forms of the latter variety, and the chance of large developments in wheat cultivation would seem to depend largely on such improvement in the Mediterranean area.

For, after all, the character of the wheat that can best be grown is determined by the climate, and in the Mediterranean area this is so definite and characteristic that it is always likely to cause an equally definite selection among the numerous kinds of wheat that are available. As applied to the whole of our area, the remarks of the Howards regarding the varieties of wheat cultivated in India are very much to the point. They say [5]:

> 'The wheats at present in cultivation in this vast Empire, in which a civilized agriculture has been practised from time immemorial, represent the survival of types most fitted for the conditions of the various tracts. Nature has eliminated the unfit, and the experience of past centuries, handed down by tradition, has taught the cultivator what soils and what tracts are suitable for this crop. Varieties of wheat introduced by sea from western countries have, in recent times at any rate, had no influence on the crop and have not been adopted by the cultivators.'

This is equally true of the wheat-growing regions of the Middle East. Attempts to introduce American varieties and hybrids from Arizona into Egypt failed completely, and after three years' work Dr. Freeman discarded all American wheats in favour of Egyptian [6], though some Australian types have more recently been fairly successful. It would seem that any development in wheat-growing in the future will have to depend chiefly, if not entirely, on the utilization of forms already growing in each section of the area, and improvement will mainly result by selection from them or by hybridization among them.

Influence of climate.—According to ancient writers in the Mediterranean region, wheat requires a rich humid earth, preferably deep valley alluvium, with plenty of ground-water, or fertile volcanic soils retentive of moisture [7]. It is also fastidious as to rain-supply at germination, and if the autumn showers hold off for a few days after sowing, there may be failure [8] as a result of the character of the Mediterranean climate; in this the great bulk of the rain falls in the winter months from November to March, whilst the summer period, May to October, is

practically rainless and generally very hot. As one proceeds east and south, the total rainfall tends to decrease till in Egypt, Arabia, and the Syro-Arabian desert, only irrigation cultivation is usually possible. There seems some reason to suppose, with Ellsworth Huntington [9], that within this general character of climate the Graeco-Roman civilization grew up in a period of increased total rainfall which lasted from about 500 B.C. to A.D. 200 and extended not only over the Mediterranean but also over most of south-western Asia. After the latter date it is suggested that there was a decline in the amount of rainfall, and especially in the autumn rainfall on which the grower depends for the sowing and germination of his crop, or that the latter, at least, became very much more uncertain. Though this theory of Huntington has not been accepted by most authorities, who consider that there is little evidence of any such change of climate [10], it seems certain that after about A.D. 200 the Middle East lost its character as the granary of the western world and was replaced at least partly by the supply of grain from North Africa. At any rate, from about this time, the Middle East tended to become less important as a wheat-growing region, till now the whole area is barely self-supporting in wheat production.

Present production.—The position at present is that the Middle East, including Turkey, Syria, Palestine, Iraq, Egypt, Iran, and Transjordan, contains units which are constant importers of wheat, and others with a small export. But the general picture is well shown by the following figures which indicate for the period 1934–7 the production and net export or import relating to each of the states. The figures, representing thousands of short tons, are approximate, but they tell the story [11].

	Total production	*Exports*	*Imports*	*Net utilization*
Egypt	1,305	..	8	1,313
Palestine	97	..	75	172
Transjordan	89	25	..	64
Syria and Lebanon	549	..	2	551
Iraq	527	58	..	469
Turkey (1937)	3,600	65	..	3,535
Iran (1934–8)	2,000	?	?	?
Total import or export	..	148	85	..

The import and export figures for Iran are not available. Most of the smaller sections of the Middle East, however, absorb the whole of the net export shown above, and it is not too much to say that the area we are discussing has little or no wheat for export to other countries.

And yet wheat is almost universally grown. The writer has seen it in what would appear to be the most unlikely places, such as the wetter parts of the Turkish Black Sea coast, and it certainly forms one of the staple cultivations in all the countries. Cereals everywhere are the main crops grown, occupying up to 90 per cent. of the cropped area. The percentage of the cereal acreage occupied by wheat varies from 29 per cent. in Egypt to 64½ per cent. in Transjordan. In Turkey it is 50 per

cent. and in Cyprus 55 per cent. It is not, therefore, that wheat is not now grown, but that the total area under arable cultivation forms only a fraction of the available land, and that the general yield per acre is small almost everywhere. Of course, where irrigation is used, the yield *can* be high, as in Egypt, but even without irrigation, where the rainfall is sufficient, very large yields are actually obtained, particularly near the Sea of Marmora and in north Smyrna in Turkey and a few other places, where in fact they may be as good as anywhere in the world. In spite of the limitations caused by the Mediterranean climate, there is no doubt that wheat will grow and grow well over most of our area. With irrigation some of the greatest difficulties in wheat-growing are removed and in such cases yields may be obtained that are phenomenally high.

Areas of production.—Except in Egypt, and to a less extent in Iraq, most of the wheat is grown without irrigation. Among cereals, under such conditions, its only serious competitor is barley, which usually replaces it where the rainfall becomes too small or too uncertain for wheat; where the rainfall is satisfactory, wheat is almost always preferred as a cereal crop. In Anatolia (Turkey), though wheat is grown almost everywhere, there are three special large centres of production of wheat grain. The first lies in north-west Turkey, the second lies on a stretch across the plateau of central Anatolia, and the third between the above, stretching from Ismir northward to the Black Sea. In 1938 Turkey was credited with a wheat production of 4,300,000 m.t. as compared with 2,500,000 m.t. of barley. In Iran the valleys and basins between the ranges of the northern mountains produce heavy crops of both wheat and barley, with a centre perhaps most characteristically at Meshed. But the whole fairly well-watered fringe of the Iranian plateau is well adapted to wheat-growing, which of course disappears equally on the damp coast of the Caspian and in the dried-out deserts of the south. In Iraq the northern plains give the wheat, which disappears in the purely irrigated tracts farther south. In Transjordan and Syria the crop struggles against drought, against a vicious land system, and against the continual fear of attack from the nomads of the south. But here, in the Hauran, there lies one of the ancient world's sources of wheat. This is a high plateau, east of the Jordan rift, about 2,500 ft. high, where west winds from the Mediterranean give a fairly constant rainfall of about 400 mm. in winter and early spring, supplemented by considerable dews. This is an old volcanic district with lava soil, rich and retentive, overlying limestone, which at one time supported a large farming and live-stock-breeding population. It is this region which causes Transjordan to be an exporter, albeit a small one, of wheat to the adjoining areas of Palestine. For Abyssinia and Arabia we have no data as to the yield usually obtained, but we do know that there is no export from either of these countries.

The other reason why the production of wheat in the Middle East is so far below what might have been expected, even when full allowance has been made for the fact that it is grown mainly on non-irrigated land, is because there are very large areas of possible cultivation which are not cropped or are cropped only at intervals of years. Even in Turkey, only 14 per cent. of the land is cultivated every year, 14 per cent. is never

cultivated, and nearly 60 per cent. is pasture. Similar figures probably occur in all the countries, and even if we exclude the regions which are too dry or where the rainfall is too uncertain, only a very small proportion of the remaining area is actually under crop in any one year. The system of a bare fallow every 2 or 3 years is very common. In view of all one knows it is legitimate to feel that the possibilities of largely increasing the production of wheat in the Middle East are considerable. Among the countries which could contribute to such an increase, one of our greatest authorities [12] specifies Abyssinia, Iran, Arabia, and Afghanistan, and to these we could add Turkey at least.

Difficulties.—Leaving aside such semi-political questions as the existence of a vicious land system almost everywhere (by which the peasant cultivator is taxed and rented so highly that he is left with only a bare subsistence from the land, and under which any improvements made by him lead only to higher taxation and a higher rental), and the baneful influence of moneylenders and merchants, there are special agricultural difficulties that make wheat-growing a far more uncertain proposition even in the irrigated areas of Egypt, Iraq, &c., and, to a much greater extent, in the regions which depend on the natural rainfall to grow and ripen the crops, than in the wheat-growing areas of western Europe. The extreme riskiness of this crop is well shown by the production in Palestine in two successive years. In 1937 the recorded yield was 127,250 t.: in the following year it was only 44,000 t., so that in the latter year the wheat crop was only 35 per cent. of that reaped in 1937, apparently entirely caused by meteorological conditions or diseases induced by them. The report to the League of Nations on the crops of 1938 states that although there were good rains up to the New Year, 'which caused heavy and rapid growth on the coastal plains, the spring rains of early April, followed by a rise of temperature, brought a universal attack of rust (*Puccinia graminis*) which affected the wheat from Dan to Beersheba'. I quote this case as it is one about which we have full data, but similar experiences are found wherever the Mediterranean climate prevails.

Over almost the whole region we are considering wheat is planted in autumn, except at high elevations, and in some regions, like Abyssinia, with a summer rainfall. Although the durum wheats are by nature a spring crop, even they must be sown in the autumn owing to the climate. The first difficulty is, therefore, the uncertainty of the autumn rains. The sowing is determined, of course, by these, and they prevail from the latter part of September to November. The rain then increases usually in December, January, and February and begins to fall off in March and finishes in April. The early cessation of the rain is an even more serious likelihood than its late beginning, and is almost always considered as perhaps the most serious risk in the cultivation of wheat. Associated with the latter is the early arrival of the hot dry weather, which produces what the French call *échaudage* or scorch, causing the grain to shrivel either at the time of its formation or as it ripens. This often leads, in the regions of the greater summer heat, to a loss of from 25 to 40 per cent. of the crop. It is usually produced as the result of intense sun

accompanied by dry winds following a period of damp weather favouring vegetative growth. It is especially prevalent on soils that are badly worked, shallow, impervious, or wet [13]. The damage from this cause is specially severe where the early spring temperature is high, some authorities stating that it becomes serious only when this exceeds 32° C. Frosts, especially late frosts in the spring, often cause serious damage, and may lead to a violent attack of rust, whilst excessive rain during the winter may lead to the same result. In fact the frequent occurrence of rust is perhaps the most important factor in determining whether wheat can or cannot be grown and the type which is most suitable for any particular set of conditions.

Wheat Cultivation in the Individual Lands of the Near East

Turkey.—Turkey is by far the largest producer of wheat in the Middle East. On the average of the years 1934–8 there were 8·5 million acres with an estimated production of 125 mn. bu. of grain. There is no country in the Middle East where more energetic measures have in recent years been taken to raise the standard of cultivation of the crop to a much higher level than prevails at present. All parts of the country grow wheat except a few areas on the Black Sea coast and some of the high level districts like Kars in the eastern highlands, but the concentration is greatest in the west of Anatolia and in the central plateau. Wheat accounts for about a quarter of the value of the agricultural produce of the country. The area under wheat increased by 25 per cent. between 1929–33 and 1934–8.

The dominant wheat is *T. durum* or durum wheat, but there are also grown large areas of *T. compactum* or club wheat, which occupies about 13 per cent. of the area under the crop. In the eastern regions large areas of *T. vulgare* are grown, which is nearly all a genuine spring wheat and a few years ago occupied one-third of the area covered by other types. One of the greatest hindrances to the development of wheat cultivation in Anatolia is the very great mixture of types that are grown together. The fields of wheat are nearly always mixed with rye, often with barley and oats, whilst the mixture of durum wheats, club wheats, and soft wheats is universal. Improved strains of wheat have been discovered by the Government research stations, and their use is gradually being extended. Great efforts have been made to replace spring wheats by winter wheats where this is possible on account of the greater yields thus obtainable. This work is not easy in a peasant country. There is no shortage of land, though the holdings are small, and the usual method of cultivation in the past has been to leave the land fallow every second year.

Among wheat diseases rust, both *Puccinia graminis* and *P. rubigo-vera*, is common, especially after cold rain in winter if this is long continued, or if the crop is grown in wet lands, whilst a damp spring is fatal owing to the increased incidence of this disease. Smut (*Ustilago tritici*) is almost universal, especially on spring wheats.

It is difficult to see how very much more can be done than is being done to extend the cultivation of wheat in Turkey and to increase its

productivity, without very far-reaching changes in the organization of agriculture. But everything that the writer has seen seems to show that there is no *agricultural* reason why Turkey should not again be one of the granaries of the world. The fact that in certain areas a yield of 25 to 30 bu. per acre is common (in the Van district it is stated that over 60 bu. per acre have been reaped) shows what can be done and how the yields obtainable are comparable with those secured in the best parts of western Europe.

Atatürk was especially identified with attempts to popularize the best methods of cultivation, and the peasants have been freed of tithe and some other taxes. But the burden of taxation is still very heavy. On the other hand, the Agricultural Bank guarantees a fixed price for wheat by its own purchases, and there are arrangements for credit. The wheat so bought is stored in silos and sold later on the Bank's account.

Syria and the Lebanon.—In this area there are mountains close to the coast, and an undulating plateau to the east running down to the Tigris–Euphrates basin. The amount of winter rain decreases rapidly from Lebanon to Syria, but the Bekaa valley between the Lebanons grows large areas of winter cereals and pulses. Syrian agriculture is primarily cereal production, and a characteristic feature is the long fields cultivated in strips by communal villages. The usual rotation is wheat, fallow, and lentils or vetches. The north-east corner of Syria is fertile with good winter rains, sufficient for wheat, and this was one of the granaries of Rome: now only relatively small areas of it are farmed. As one proceeds from the irrigated areas round Damascus into the deserts at the east and south, the sequence is dairying, olive and fruit plantations intercropped with cereals, vines, cereals alone, and desert.

The cultivation consists almost exclusively of durum wheat, and the most frequent type is a reddish one termed *haurani*. It is sown in October and November and reaped in May or June. In the north the chief difficulties encountered are: (1) a low winter temperature, often as low as $-10°$ C.; (2) drought during March and April; (3) frosts during March; and (4) hailstorms in spring. Of these by far the most important is the lack of rain in March and April, with drying winds and high temperature. The other difficulties are comparatively rare, but there have been cases, even in recent years, when almost the whole of the wheat crops were lost owing to frosts both in winter and in spring. The uncertainty of the climate is shown by an estimate [14] that in central Syria out of 10 years there will be 3 bad on account of drought and *échaudage*, 4 years about average, and 3 years with a good and satisfactory yield.

Most of the wheat is grown without irrigation, but where water is available it is often used, as in the neighbourhood of the Euphrates and in the Lebanon valleys.

Palestine.—Passing from north to south in Palestine, the rainfall decreases in the coastal plain from 20 to 10 in., in the Jordan valley from 20 to 2 in., and in the central range from 35 to 25 in., but the annual variation is considerable and ranges from half to double the average. The most general system of agriculture is a 2-year rotation. The winter

crop is wheat or barley, and is rotated with a winter leguminous crop or with a summer crop in the succeeding year such as *durra* (sorghum) or sesame. A 3-year rotation is also in use. There is little manure applied and what might be used is often sold to citrus plantations.

In this typical area of the Mediterranean climate we have two well-marked periods of precipitation. The 'former rain' in October and November is not usually large, but it increases in December, January, and February, begins to fall off in March, and finishes in April. There is a moist W. or SW. wind in winter, dry N. or NW. wind in summer. The dreaded sirocco from south and east comes in April and May and sometimes in September and October. But both at the beginning and end of the wet season the rain becomes doubtful, and it is not so much a deficiency in quantity as this fact which causes the very great differences in its effectiveness. Thus, for example, in 1938 although the aggregate rainfall was somewhat above the average, the irregularity in its incidence together with a serious and widespread outbreak of rust resulted in yields of both wheat and barley that were most disappointing both in quantity and quality.

Most of the wheat grown is durum, as this is more resistant to rust and also to drought. It is, as usual, hopelessly mixed and the agricultural department has made great efforts to obtain and spread purer stocks. In 1937–8, 187,700 kg. of such seed were distributed. The sowings begin in November and continue up to the end of January. The harvest dates from about the middle of May, being later in the north than in the south. Complaints are frequent of failure due to lack of rain in the autumn. If there are less than 70 mm. of rain in the two sowing months, there is likely to be failure. This occurs in 40 per cent. of years at Jaffa. Equally difficult is the lack of rain at the critical period of March and April, and if this is accompanied by the sirocco winds, there is bound to be large-scale complete loss, and what is not lost by shrivelling of the plants may be lost by scorching of the ears (*échaudage*).

Transjordan.—This country, including the portion in Syria, was once one of the granaries of Rome and supported a highly developed and advanced population of about a million people—three times its present primitive and backward population. The region's agricultural and cultural development reached its greatest height under the Nabateans before the second century A.D.; subsequently it was dominated by the Roman and Byzantine empires, and finally blotted out by the Arab invasions beginning in the seventh century [15].

The climate is essentially subtropical and steadily gets more and more arid as one proceeds to the east and south. In the Jordan valley wheat and barley are grown under irrigation, and a rotation of wheat in the winter and white *durra* (sorghum) in the summer is common. The plateau region to the east of this was where the great supplies of wheat were raised at one time, the climate being typically Mediterranean, having a rainy season lasting from October to May and a long dry summer season from May to September. But it is very irregular, and Lowdermilk [15] notes that 'reliance of farming and grazing on regularity of rainfall has often brought disaster to man and beast alike'. It is

evident that this irregularity must be taken into account in any attempt to regain some of the wheat-growing capacity that the region formerly possessed.

Iraq.—The great possibilities for wheat culture of the upper valley of the Euphrates in Turkey have already been mentioned. This area extends far to the east right up to the edge of the Iranian plateau, and wheat is a large crop as far south as the 36° N. parallel. To the south of this wheat gradually disappears. In all this area, with a strongly continental climate, including the possibility of very great cold in winter but a certainty of great heat in the spring, and with a likelihood of severe drought when the corn is ripening, wheat is cultivated under great difficulties and only varieties which have been developed in the area can stand the conditions. Even as it is, the spring drought and the accompanying heat often lead to shrivelling and *échaudage*. The possibilities of irrigation in these regions are rather limited, and in any case it seems likely that durum wheats will be of the greatest importance, or some types of common or club wheats which have been developed for similar climatic conditions elsewhere.

Iran.—Except in the higher mountain regions, where spring wheats are grown without irrigation, wheat in Iran is almost entirely an irrigated crop. Hence, though wheat and barley are the predominant crops in the country, the normal system of cultivation is to leave a considerable proportion of the land in fallow largely because water is limited. Only from 10 to 15 per cent. of the land is cultivated, but a further 20 to 30 per cent. could be cultivated if water were available. The extent of wheat cultivation is therefore very largely dependent on the abundance of the autumn and winter rains in the mountains bordering the Iranian plateau giving a sufficient amount of water for adequate irrigation. At the same time, if water is abundant and applied too freely, there ensues a bad attack of rust.

Winter wheat is usually sown in the latter part of October: if delayed till late in November, there is danger on the high plateau of Iran that the winter frosts will damage the wheat. Irrigations are further given from February onward and harvest takes place from June onward.

In Iran we are approaching what appears, according to Vavilov [16], to be the centre of origin of *T. vulgare* and *T. compactum*, and hence these are more commonly grown than is usual in the Mediterranean climate of the other countries of the Middle East. But they are restricted by the extreme susceptibility to rust of most of their strains, for in such areas as Fars and Kerman, where rust is very common and serious, they have to give place to less sensitive types.

Afghanistan.—The cultivation of wheat in Afghanistan has been studied in great detail by Vavilov [17], who finds here the centre of distribution of *T. vulgare* or common wheat, and of *T. compactum* or club wheat. Durum wheat does not occur even in admixture (Vavilov). Dry wheat, i.e. non-irrigated, is composed entirely of common wheat; irrigated wheat consists almost entirely of club wheats. Both soft and club wheats as grown in Afghanistan are very subject to brown, yellow, and black rust, and smut is very common indeed. Spring wheat is grown up

to an elevation of over 10,000 ft. and winter wheat up to over 9,000 ft. It is impossible to give any idea of the yields usually obtained, but they are almost certainly small, and the wheats, as grown, are almost hopeless mixtures of varieties.

Egypt.—The cultivation of wheat in Egypt is among the most interesting in the whole of the Middle East. It is all irrigated either by basin, water being applied during the river flood only, or by canal, 2, 3, or 4 irrigations being given during the growth of the wheat. The chief wheat grown is *beladi*, a durum wheat, occurring in both red and white forms. The so-called Hindi wheat, which is grown only on canals, is a soft wheat brought from India and is less mixed than those of local origin, but it has proved very susceptible to rust. Of late years some varieties have been introduced from Australia, and have given excellent yields under canal irrigation. Most wheats are sown from October to the first half of December, and are reaped in May or the first half of June.

There is no doubt that the great enemy of wheat-growing in Egypt is rust. Foaden and Fletcher stated that rust was rarely serious, but that is hardly so now. Balls also states that rust does little damage to cereals, as the local wheats are naturally immune. Nearly all more recent writers lay stress on its importance, and it is said that even local Egyptian wheats are severely attacked by yellow rust. Azzi [14] states that rust and other maladies (chiefly smut) cause 80 per cent. of the serious damage to the wheat crop in Egypt.

Abyssinia and Eritrea.—In Abyssinia, which Vavilov considers as the most probable centre of distribution of durum wheats, and where 75 per cent. of the wheats cultivated consist of this variety, we have a region of summer rains where, after slight falls in March and April, the main rainfall is received in June to September. The country is generally well watered and is of high fertility, and the standard of peasant cultivation is high. There is little doubt that Abyssinia could be a large producer of wheat for world use if transport facilities existed for its movement in and out of the country. All the wheat is grown as a summer crop, and is usually sown in May or June and reaped from October to December.

In Eritrea there is a summer rainfall of 20 in. on the north and south plateaux and about 12 in. on the western plains. A recent observer informs the writer that although there is a genuine agriculture on the south plateaux, the land is not fertile except in spots, and most of the people are warriors and not farmers. On the northern plateaux, on the other hand, the people are nomad pastoralists. The western plains are the most immediately capable of development, and this is being done largely by Sudanese and West Africans.

Conclusions

This survey of the cultivation of wheat in the various countries of the Middle East indicates that so far as climate and soil are concerned wheat-growing could be greatly extended, and that there is little to prevent its becoming again an important factor in the world's supply of this cereal. But to do this several things are needed.

First, unmixed varieties of wheat must be grown. Everywhere it is complained that the peasants are using seed which is a hopeless mixture of types, even when it does not contain rye, barley, and oats. This necessity has been recognized by the agricultural departments in almost all the Middle East countries, and their energies have been concentrated on producing and spreading selected seed among the wheat-growers. Such work is slow and wearisome, but considerable success has been achieved in Turkey, Egypt, Palestine, and several other countries. At the Karej station in Iran they have as many as 1,500 varieties on trial, with facilities for multiplying those which prove themselves valuable.

Not only is it necessary to provide unmixed varieties, but they must be at least fairly resistant to rust, that curse of wheat-growing in the whole of the Middle East. Resistance to rust depends also on the prevalence of good agricultural conditions and particularly on the absence of waterlogging of the land owing to lack of drainage or to excessive winter rains. Rust may also follow late frosts in the early spring, a contingency which can hardly be provided against except by the development of varieties which ripen early.

Early ripening is also important as a protection against *échaudage* due to hot dry winds at the time of grain formation or ripening. The writer is not aware that very much attention has been given to this matter, but in view of the great amount of damage said to be produced in the greater part of the area every year, it would seem to be one of great importance.

Manuring is important if more than 11 or 12 bu. per acre are to be obtained, even with the best of climatic conditions. It is one of the dangers of the extension of intensive cultivations, like that of citrus in Palestine, that it drains the surrounding country of its manure, and such crops as wheat suffer in consequence. But unless a very frequent fallow is given (and this means the waste of much of the land from the point of view of production) high yields are impossible without the use of a good deal of manure, especially nitrogenous manure, whether derived from organic or other sources.

In view of the paramount importance of water-supply both in the autumn and in the early spring for wheat cultivation in a Mediterranean climate, and of the irregularity of rainfall in most of our area, the importance of water conservation can hardly be overstressed. It is perhaps the uncertainty of the rain in the spring that is the biggest cause of failure of the wheat crop, and so the use and development of early maturing strains of wheat affords the most likely method of meeting the difficulty. How far the method of vernalization worked out by Lyssenko and other Russian investigators has been applied to wheat in Turkey and other Middle East countries is unknown to the writer, but if even a fortnight could be gained in the spring it would be of enormous importance in securing a far more certain crop than is now possible. Apart from these methods, all arrangements for checking soil erosion and retaining water in the soil should be of considerable value, and what has been already done on the Jewish colonies in Palestine gives a lead to workers in other parts of the Middle East. The way in which the methods of so-called 'dry farming' have been applied in India are well

worth study by those who wish to increase the chance of high yields in the more doubtful areas of the countries under study [18].

The more the situation is studied, both in the Middle East and in the other peasant countries of the world, the more one feels that if agriculture, and specially wheat-growing, is to be pursued on a more reliable basis than it is now or has been in the past, one of two things must happen: either peasant cultivation must be abandoned, or a thoroughgoing system of co-operative work by the peasants must be substituted for the purely individual action that now exists. This is not the place to develop this thesis, but a long experience in several peasant countries of Asia has convinced the writer that there is hardly any third alternative if a sound agriculture, with a basis of wheat-growing, is to fit into the world-system of the future.

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A PLAN OF GROWTH, MATURITY, AND YIELD OF THE POTATO PLANT

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Two recent papers [1, 2] have included critical references to a statement in one of my publications [3] on the effects that a sub-tropical or tropical environment is likely to have on the yield of commercial varieties of potato. The possibility of widely divergent viewpoints on this important problem indicates that in spite of the number of publications about growth, yield, and photoperiodic reaction of the potato, there are few pertinent data from which to decide this and similar issues. According to their point of view, investigators are likely to advocate as the determinant of yield single causal agencies from amongst two or more, which may form an interacting complex of causal agencies. Further, it is difficult to assess what phases of plant development are affected by changes in the environmental complex. The mechanism of growth in the potato plant is so little understood that modifications of the balance of growth, which affect tuberation and yield, cannot yet be properly estimated or predicted.

The great need is for valid generalizations about the growth of the potato plant. This need has been apparent in much of the work on potato diseases and pests, attempted in recent years by the Council for Scientific and Industrial Research at Canberra, for which growth-measurements of the potato plant have been needed as primary or ancillary data. Data on growth have been accumulated, some of which have already been published [4, 5]. Also, an attempt has been made to find generalizations that will contain all the more important facts emerging from these measurements and observations. The generalizations that have been made cannot yet be shown to meet the essential requirement of validity, but there is much evidence in their favour, and they have been so useful in our own work that they may have some value for investigators working directly, and not incidentally, on problems of growth, maturity, and yield.

The general plan of growth, applicable to the varieties of potato of which we have had experience, is founded on the principle of competition for the available metabolites between the various organs of the plant. The partition of metabolites between organs may be governed by hormones or growth-substances manufactured in the leaves [6] or growing tips. Implicit in the plan are general assumptions, for which there is some evidence but no proof. These are:

(1) The basic efficiency of the metabolic centres is similar for different varieties of the domestic potato.

(2) Under similar environmental conditions the division of metabolites in various proportions between the organs of the potato plant induces in different varieties and strains differences in growth-form, maturity, and yield.

(3) The partition of metabolites in plants of a single variety or strain in a similar environment, but on different occasions, will be quantitatively similar; and changes in the environment will produce characteristic changes in the partition of the metabolites.

The data on which the first assumption rests are mainly serial readings of leaf-area, made during the earlier stages of growth, on different varieties of potatoes in field trials. Some results of these readings have been published [4, 5]. Leaf-area becomes a measure of the metabolic potential of the plant, if it is assumed that it is a measure of the amounts of functional protoplasm of which the metabolic centres consist. There are indications in physiological literature [7] that this assumption is reasonable for plants related to the potato during the earlier stages of growth.

The second and third assumptions rest on evidences of similarity and difference in growth-form measurements. Measurements have been taken on many potato varieties mainly grown in the one small area of country (Australian Capital Territory). Additional qualitative observations have been made in widely different environments.

Many of the data suggest an equivalence between quantities of tissues formed in different organs, for example in leaves and tubers. An equivalent value that has been used in schematic comparisons between varieties is, during the earlier stages of growth, one square decimetre of leaf is equivalent to 6 gm. of tuber. This implies that the quantity of essential or limiting metabolites needed in the formation of 1 sq. dm. of leaf-area is sufficient to form 6 gm. of tuber tissue. These are very approximate figures and are quoted as an example, not as a precedent.

The general course of growth of the potato plant may be divided into stages. In the first stage the main shoot emerges and extends, and the leaves arising directly from the main stalk expand. There may be competition between roots and foliage at this stage, but the relative mass of the former is small. Considerable differences in the development of the root-system would not alter very greatly the amount of metabolites available for the foliar portions of the plant, unless some substance needed in approximately equal amounts by foliage and roots was limiting growth. All potato varieties so far tested [5] have a similar foliar growth-rate during this stage of development.

The main stem is terminated by a flower-head, and the numbers of nodes formed below and above ground vary little from one variety to another. Including both below- and above-ground portions, the modal value for the total number of nodes on a main stem, not submitted to severe competition from the growth of other main shoots, is, in our experience, 27. As the phyllotaxy of the potato is 13/5, this represents two complete cycles of leaves. The number 27 may be coincidental, or may be an essential feature in the initiation of the terminal flower head.

As the number of leaves on the main stem approximates to a constant value, the duration of the first stage of growth is largely determined by the average size of leaves on the main stem [5]. In a variety with large leaves, those on the main stem continue expanding after expansion of corresponding leaves on plants of varieties with smaller leaves has almost

ceased. As a result of the competition from these leaves the beginning of the second stage of development may be delayed by a period of a few days or a week.

The second stage opens with the beginning of the rapid growth of axillary shoots above ground, or below (stolons). At this stage the first important evidence of differential growth appears. In some varieties a high proportion of the available metabolites is diverted below ground, stolons grow out, tuber initials form early and swell rapidly. There is a correspondingly slow growth of shoots from the axils of the leaves of the main shoot. Opposed to this type are varieties of which the stolons grow out more slowly, and tuber initials do not form until considerably later. They swell very slowly and the initiation of new tubers may extend over a considerable period. Meanwhile, axillary shoots above ground continue to grow rapidly.

Of the total metabolites diverted to axillary growth above and below ground, shortly after the inception of the second stage of development, the proportion going to the foliar axillaries is at a relatively high value. The proportion declines more or less rapidly as increasing amounts of metabolites move to the tubers, and finally it approaches or reaches zero. At this stage the foliar portions of the plant have reached their greatest size, and a negligible quantity of new foliar tissue is thereafter added by the plant.

The second stage of development thus begins with the initiation of rapid axillary growth (either above or below ground), and ends when the total foliar portions of the plant attain their maximum leaf-area. In general, this period is shortest in varieties with the highest initial partition ratios of metabolites (partition coefficients) in favour of the tubers, and longest in varieties with the lowest initial partition coefficients in favour of the tubers. However, there appear to be individual reversals of this rule. Varieties or strains with high partition coefficients in favour of tuber formation produce small haulms, and those with low partition coefficients produce large haulms. The difference between contrasting varieties in the length of the second stage may be of the order of two months under our local environment; and the difference in leaf-area, expressed as a ratio, may be as high as 10 : 1. It is the partition ratio of metabolites in this stage that mainly determines the size of the haulm and largely, but not in such a high degree, determines maturity.

Although during the second stage of development the growth of the roots is probably another factor in the competition between organs, differential rates of root-development do not appear very greatly to affect the course of growth of the above- and below-ground axillary organs except in strongly contrasting varietal types. Again the reason appears to be the relatively small quantities of food materials needed for root-development.

The third stage of growth corresponds with what is generally known as the senescent stage. It occupies the period from the time when the potato haulm reaches its maximum size until the haulm and roots are dead and the tubers are fully formed. It may include a more or less static period when currently formed metabolites are descending into the

tubers and the quantity of foliage remains at a steady level, and, in addition, a period when the foliage is yellowing and dying, and reserve materials are descending rapidly into the tubers, i.e. when the plant is ripening. Transfer of reserve materials may, however, begin relatively early; it may even occur in a small degree before the second stage of development is complete.

The length of the third stage is at least partly independent of the length of the two earlier stages. It helps to determine the period of maturity. Thus, in a potato plant passing through its full course of development, maturity is mainly determined by:

(1) the size of leaves formed on the main stem and the consequent hastening or delay in the initiation of above-ground and below-ground axillary growth;

(2) the initial partition ratio of metabolites between foliar axillary shoots, and stolons and tubers;

(3) the rate at which the partition coefficient for metabolites passing to the foliage declines, and the time at which the potato haulm reaches its maximum size;

(4) the length of time during which the size of haulm remains static and current metabolites descend to the tubers; and

(5) the rate at which reserves of food materials in the foliage and roots are mobilized and translocated to the tubers.

Apart from environmental limitations to growth such as water-supply, and competition between plants and between main shoots arising independently from the same sett, the yield is determined by the internal influences summarized below. As previously stated, it is assumed that the metabolic efficiency of different varieties under similar conditions is similar. Therefore, equal quantities of leaf-tissue will produce equal quantities of metabolites, some of which will produce new functional foliage and root-tissue and reserves stored in the foliage and roots, some of which will go directly to the stolons and tubers. A given quantity of metabolites will be needed to form so much leaf-tissue, so much root- or tuber-tissue; and there will be reasonably constant ratios between the amounts of these different tissues formed by the same quantity of metabolites.

(1) Determinants of yield will be the initial partition coefficients for metabolites divided between tubers and axillary shoots, and to a lesser extent the root-system, and the rate at which the partition coefficient for tubers approaches or reaches unity, i.e. when all or nearly all currently-formed metabolites are descending to the tubers. These determine the quantity of functional leaf-tissue exposed, and the period of its exposure during the second stage of development. The partition coefficients will thus determine yield up to this stage. The relative size and efficiency of the root-system of different varieties appear to have relatively little effect on the quantity of metabolites formed in good growing conditions; but in unfavourable growing conditions they might become limiting at different levels, and introduce differences in yielding capacity.

(2) The next determinants of yield are the amount of functional leaf-tissue exposed during the third stage of development, and the time of its exposure. The former may not be directly proportional to the total amount of leaf-tissue exposed, as the mobilization and translocation of the reserve food-stuffs in the leaves may encroach on the available metabolic energy, and even on some of the materials of which the metabolic centres are composed. Apart from this it is convenient to assume that the efficiency of the metabolic centres in the manufacture of current metabolites will be of the same order as in the second stage of growth.

(3) The last determinant of yield is the amount of reserve materials stored in the foliage, and this in turn will depend on the size of the haulm. These materials are probably a less efficient source of food-stuffs for storage in the tubers than currently formed metabolites, because extra energy and materials must be used in the anabolic and katabolic changes occurring during the double act of storage and translocation. Extra energy must also be used in the production of additional tissues, such as the fibrous portions of the stems and leaves, that are not converted for use in the composition of tuber-tissue.

A comparison between the growth-characteristics of two commercial varieties of potato may help to illustrate how the point of view provided by this plan aids an understanding of the phenomena of maturity and yield. Katahdin was originally listed as a late variety [8]; in Australia it has a high ratio of tubers to foliage: the Tasmanian variety Bismark is vigorous, medium early, and high yielding. Katahdin has a high partition coefficient for metabolites passing directly to the tubers. Tuber initials are formed early and swell rapidly, and axillary shoots are small and do not grow rapidly. In a cool, temperate climate, axillary growth continues longer than would be expected from the high initial tuber partition coefficient. This and a long period during the third stage of growth, when the leaf-area alters little and ripening has not begun, bring Katahdin into the category of mid-season or late varieties. In a hotter climate at lower latitudes the second and third stages of development are shortened, and Katahdin becomes an early variety because of its high initial tuber partition coefficient. The yield of Katahdin in relation to the size of haulm is high, but it is frequently outyielded by varieties of similar maturity that develop a larger haulm. The increased leaf-area of such varieties results in the formation of a greater total of metabolites. These varieties may produce a greater total weight of tubers in spite of a lower tuber partition coefficient; in spite also of a lower efficiency resulting from the building of extra foliar tissues, the storage of reserve food material there, its conversion, and translocation before it can be stored in the tubers.

Bismark is of the second type. Its partition coefficient for metabolites passing to the tubers is, for an early variety, low, the plants produce their first tuber initials relatively late, and the tubers at first grow as slowly as those of many late varieties. The plants develop relatively large haulms, and this and the length of the second stage of growth do not suggest an early variety. However, once the foliage has reached its maximum leaf-area, the third stage of growth is initiated and accomplished in an unusually short time. When Bismark plants develop in a

cool, temperate climate, they mature more quickly than Katahdin plants. In a hotter climate at lower latitudes they may be later maturing than Katahdin plants, possibly because their lower tuber partition coefficient prevents such a radical shortening of the later stages of development as Katahdin undergoes.

If a study of this differential effect of environment on the growth of potato varieties were undertaken, the plan of growth outlined here would suggest fairly clear-cut lines of inquiry, e.g. which of the environmental factors, length of day, light intensity, temperature or humidity affected the partition ratio between tubers and axillary shoots, or the induction or the length of the third period of development. Such questions should lead to a clearer understanding of the effects of environment on growth than a more general inquiry on how the environmental factors affect maturity and yield.

Most of the ideas which make up this plan of growth are familiar to plant physiologists. Students of heterosis will recognize the similarity between the early growth of the potato and a corresponding stage in the growth of maize and tomato plants [9, 10]. Competition between organs has been observed in the potato [11] and many other plants; the literature on growth substances is permeated by it. However, these ideas do not appear from the available literature previously to have been associated and applied to the growth and development of the potato plant.

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THE ROTHAMSTED EXPERIMENTS ON MANGOLDS, 1876–1940

PART IV: THE COMPOSITION OF THE MANGOLDS GROWN ON BARNFIELD; (i) THE DRY-MATTER CONTENT OF LEAVES AND ROOTS

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THE dry-matter content of the produce of some plots of Barnfield was measured in every season from 1876 to 1914, but in only a few seasons were determinations made for every plot in the field. The mean dry-matter contents of leaves and roots at harvest for the years for which complete records exist are shown in Table 1.

TABLE 1. *Mean Dry-matter Content of Mangolds as per cent. of Fresh Weight, Barnfield*

Leaves, 1876–83 and 1902 (9 years)

	Series	Strip 1 FYM	2* FYM+P	4 PKNaMg	5 P	6 PK	8 No minerals	Mean
O	No nitrogen	10·3	9·8	10·0	10·1	11·0	11·2	10·5
N	Nitrate of soda	10·1	9·8	8·8	9·8	9·8	9·3	9·7
A	Sulphate of ammonia†	9·7	10·0	8·8	10·3	9·8	10·2	9·8
AC	Rape-cake and sulphate of ammonia†	9·3	9·9	8·6	11·1	9·9	11·2	10·0
C	Rape-cake	10·0	10·1	8·9	11·8	10·8	12·0	10·7
	Mean	9·9	9·9	9·0	10·6	10·3	10·8	10·1

Roots, 1876–90 (excl. 1885) and 1902 (15 years)

	Series	Strip 1 FYM	2* FYM+P	4 PKNaMg	5 P	6 PK	8 No minerals	Mean
O	No nitrogen	13·7	13·4	15·1	15·1	15·3	15·8	14·8
N	Nitrate of soda	12·4	12·1	12·8	12·6	13·2	12·9	12·7
A	Sulphate of ammonia†	12·5	12·4	13·4	14·4	14·0	14·7	13·6
AC	Rape-cake and sulphate of ammonia†	12·2	12·4	12·4	13·3	13·2	13·5	12·9
C	Rape-cake	12·9	13·1	12·8	14·3	13·7	14·3	13·6
	Mean	12·7	12·7	13·3	13·9	13·9	14·2	13·5

During the period to which the table refers, strip 7 received the same treatment as strip 6, with the addition of a very small dressing of nitrogenous fertilizer. The results for strip 7 were almost identical with those of strip 6 and have been omitted from the table.

* In 1902 this strip received potash in addition to farmyard manure and phosphate.

† Actually, 'ammonium salts' consisting of equal weights of sulphate and muriate of ammonia.

The most obvious effect of the mineral fertilizers on the dry-matter content of the leaves is the depression caused by the mixture of sodium and magnesium salts (comparison of strips 4 and 6). Potash had a similar but much smaller effect, except in the absence of nitrogen. The effect of phosphate applied alone varied with the nitrogenous dressing, but on the average it caused a small reduction. Nitrogenous fertilizers, with the exception of rape-cake, also depressed the dry-matter content slightly.

The results for the roots differed from those for the leaves in that the effects of sodium and magnesium salts and of potash were smaller, whilst those of the nitrogenous fertilizers were greater. Rape-cake, in its effect on the root, behaved like the other nitrogenous fertilizers. Nitrate of soda caused a greater reduction of dry-matter content than did sulphate of ammonia, whereas their effects on the tops were almost identical.

Farmyard manure, like the nitrogenous fertilizers, caused a marked reduction of the dry-matter content of the roots, but only a slight reduction in the leaves. Phosphate applied in the presence of farmyard manure had no effect.

These results show that, in general, fertilizers and farmyard manure all tended to reduce the dry-matter content and to increase the water-content of mangolds. The effects were rather small, the largest being those of the mixture of sodium and magnesium salts on the leaves, and of nitrogenous fertilizers on the roots.

Since all fertilizer treatments tend to reduce dry-matter content and to increase yield, there is an inverse relation between dry-matter content and yield, the produce of high-yielding plots, i.e. large plants, having a low dry-matter content and vice versa. This is shown for the roots in Fig. 1. Nevertheless, fertilizers appear to have specific effects on dry-matter content, which are independent of their effect on yield; for example, the mean yield of roots on plot 1–C was more than double that on plot 8–N, yet the mean dry-matter contents were identical.

Seasonal variation of dry-matter content.—The records are too incomplete to allow a detailed analysis of the causes of seasonal variation in dry-matter content to be made, but some of the more obvious relationships have been investigated. Table 2 shows for a few selected plots of widely differing treatment that, in the years for which data are available, the range of seasonal variation in the dry-matter content of the roots was considerably greater than that induced by variations in manuring (Table 1).

The magnitude of the difference between the highest and lowest values of dry-matter content is similar on all the plots. The variability, as measured by the Standard Error, does not appear to be related to mean yield or mean dry-matter content.

The inverse relation between dry-matter content and yield shown by the means for the different plots (Fig. 1) apparently does not hold for the variations between seasons on individual plots. The regression coefficients of dry-matter content on yield of roots in different seasons (Table 3) calculated for five representative plots, though all negative, are far from significant except that for the unmanured plot 8–O. On this plot there was a tendency for high dry-matter contents to occur in

TABLE 2. *Seasonal Variation of Dry-matter Content, as per cent. of Fresh Weight, of Mangold Roots, Barnfield*

Plot	*Treatment*	*Mean yield of roots, tons per acre, 1876–94*	*Mean dry matter per cent., 1876–90 and 1902*	*Range of dry matter per cent.**	*S.E. of dry matter per cent.†*
8–O	Unmanured	3·78	15·8	13·1–18·5	1·35
4–O	Complete minerals	5·34	15·1	11·7–17·1	1·30
1–O	Farmyard manure	16·77	13·7	10·7–16·0	1·18
4–N	Minerals and nitrate of soda	18·30	12·8	9·5–16·4	1·41
2–AC	Farmyard manure, rape-cake, sulphate of ammonia and superphosphate	23·46	12·4	8·9–15·5	1·38

* In all available years between 1876 and 1914. The years differ for the different plots.

† S.E. for a single year.

TABLE 3. *Regression Coefficients of Dry Matter, as per cent. of Fresh Weight, on Yield of Roots in Tons per acre, in different Years, Barnfield*

Plot	*Treatment*	*Regression coefficient*
8–O	Unmanured	$-0{\cdot}548 \pm 0{\cdot}166$
4–O	Complete minerals	$-0{\cdot}003 \pm 0{\cdot}132$
1–O	Farmyard manure	$-0{\cdot}065 \pm 0{\cdot}038$
4–N	Complete minerals and nitrate of soda	$-0{\cdot}021 \pm 0{\cdot}033$
2–AC	Farmyard manure, rape-cake, sulphate of ammonia and superphosphate	$-0{\cdot}050 \pm 0{\cdot}031$

years of low yield, and vice versa, but on the other plots the seasonal variation of dry-matter content was independent of yield.

It is reasonable to suppose that the dry-matter content, or, more obviously, its complement the water-content, of the mangold would vary with the rainfall during the growing season. This was tested by fitting a multiple regression of dry-matter content on rainfall during the three periods May–June, July–August, September–October. For this purpose the mean dry-matter content of the roots of 25 plots—1, 2, 4, 5, and 6 of Series O, N, A, AC, and C—was calculated for each of the 25 years during the period 1876–1902 for which complete records exist. The mean of a large number of plots was used so as to minimize the effects of varying weather conditions during the period of harvest, which in some seasons lasted as long as 3 weeks. The regression coefficients of mean dry-matter content of the roots on rainfall during the three periods, expressed as dry matter per cent. per inch of rain are:

May–June rainfall	$0{\cdot}115 \pm 0{\cdot}137$
July–August rainfall . . .	$0{\cdot}054 \pm 0{\cdot}115$
September–October rainfall . .	$-0{\cdot}165 \pm 0{\cdot}081$

The coefficients for May–June and July–August rainfall do not exceed their standard errors, but that for September–October rainfall is significant. The regression coefficient on September–October rainfall alone, omitting the two earlier periods, is slightly greater, $-0{\cdot}187 \pm 0{\cdot}077$. Thus, rain falling during the period May to August had no detectable effect on the dry-matter content of the roots at harvest, but later rainfall during September and October reduced the dry-matter content and

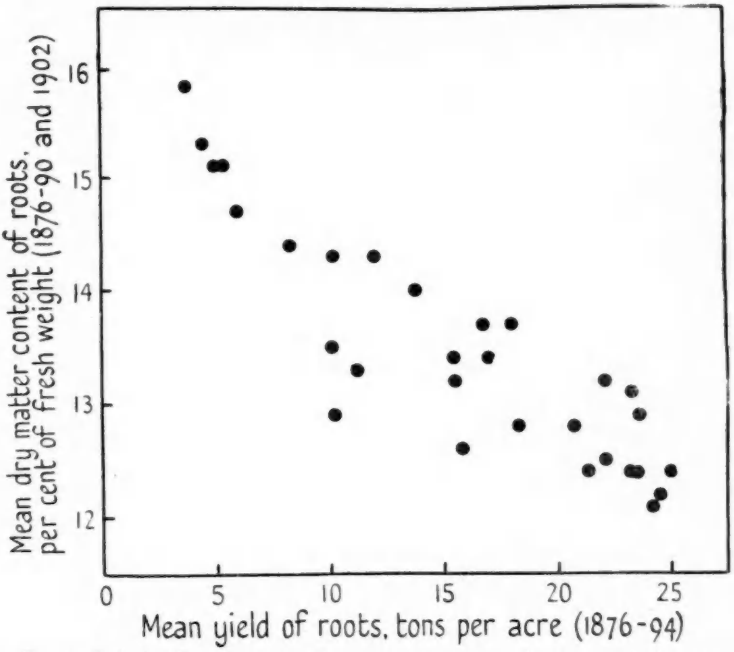

FIG. 1 Relation between mean dry-matter content and mean yield of roots on the different plots of Barnfield.

increased the water-content. September rainfall apparently had a slightly greater effect than October rainfall, possibly because the crop was harvested before the end of October in 6 of the 25 years; the regression coefficients on rainfall during these two months taken separately are:

September rainfall	$-0{\cdot}252 \pm 0{\cdot}118$
October rainfall	$-0{\cdot}181 \pm 0{\cdot}130$

A similar investigation on the dry-matter content of the leaves failed to show any significant correlation with rainfall during any of the three periods. The reason is possibly that the water-content of the leaves is much more dependent on conditions at or immediately before harvest than that of the roots. The water-content of the leaves may be affected by the presence of surface moisture deposited by rain or mist just before

or during harvest, and it is also subject to large diurnal variation. The dry-matter content recorded for the leaves on any plot will, therefore, depend on the time of day at which the plot is harvested. Watson and Baptiste [1] found that on the average of a number of sampling occasions, the leaf laminae of mangolds lost 11 per cent. of their mean water-content between 10.0 a.m. and 4 p.m., whilst the loss from the roots during the same period was only 0·2 per cent. of the mean water-content.

The water-content of the crop, especially of the roots, at any time is probably determined mainly by the soil-moisture content. This depends not only on rainfall, but also on the loss of water by drainage, evaporation, and transpiration through the crop. The extent of these losses is affected by other weather factors, notably temperature. Thus rainfall is only one of a complex of factors which influence the water relations of the crop, and it is not surprising, therefore, that the correlation between dry-matter content at harvest and rainfall in different seasons is not very close.

Variation of water-content during the growing season.—Watson and Baptiste [1] showed that the variations in water-content of a mangold crop at intervals throughout a growing season were well fitted by a regression on accumulated rainfall and time. The time-term of the regression was interpreted as an indirect measure of the rate of water loss from the soil, but it also takes account of any steady drift of water-content due to internal changes in the plant. The two terms together thus measured the balance between the gain and loss of water from the soil, i.e. the change in the soil-water content. The change of water-content associated with unit change of soil moisture, estimated in this way, was found to be much greater in the leaf lamina than in the petiole or root, presumably because the petiole and root have greater mechanical rigidity than the leaf lamina. The average rate of loss of water from the soil, calculated from the regression equations, corresponded to 0·6 in. of rain per week, and estimates of this rate of loss derived from the equations for lamina, petiole, and root were very similar, as would be expected if the assumption that the time-term of the regression measures the rate of water loss is correct. It follows that the total water loss from the soil during the period of observation from mid-July to the end of November was equivalent to about 11 in. of rain. Presumably the greater part of this water was transpired by the crop, for at this period of the year drainage and evaporation from the soil are likely to be small. It is noteworthy that the total rainfall during the same period was 8·7 in., so that for this particular crop and season (1934) about four-fifths of the crop's water-requirement was supplied by rain falling during the growing season, and about one-fifth was drawn from the supply already in the soil.

The sugar-content of the roots.—Determinations of the sugar-content of the roots were carried out systematically on the produce of 25 plots (1, 2, 4, 5, and 6 of series O, N, A, AC, and C) of Barnfield during the four seasons 1877–80, and the results were summarized by Lawes and Gilbert in their 1895 paper [2]. Analyses for a few plots were made in the years 1895–9, and in 1900 and 1902 they were repeated for the same 25 plots as in 1877–80. In later seasons the sugar-content has not been

determined. The results for 1900 and 1902, given in Table 4, are reproduced, with some modification, from Hall's account of the Barnfield experiment [3]. As the earlier records show similar fertilizer effects, they are omitted from this discussion.

Nitrogenous fertilizers caused a large reduction of sucrose as per cent. of fresh weight, which increased with increase in the rate of nitrogen supply (cf. series AC with series N, A, and C). Potash increased sucrose as per cent. of fresh weight slightly, whilst the mixture of sodium and magnesium salts, applied in the presence of potash, caused a reduction which more than counterbalanced the increase produced by potash. A similar effect of sodium is apparent from the comparison of nitrate of soda and sulphate of ammonia; nitrate of soda caused a greater reduction of sucrose-content, presumably because it supplies sodium as well as nitrogen. Farmyard manure, like the nitrogenous fertilizers, depressed the sucrose-content.

When sucrose-content is expressed as per cent. of dry matter, these fertilizer effects still persist, but the nitrogen and sodium effects become

TABLE 4. *Sugar-content of Mangold Roots, Barnfield.* (*Mean of 1900 and 1902*)

Strip	1 FYM	2 FYM +PK	5 P	6 PK	4 PKNaMg	*Mean*	1 FYM	2 FYM +PK	5 P	6 PK	4 PKNaMg	*Mean*
	SUCROSE											
Series	Per cent. of fresh weight						Per cent. of dry matter					
O•	8·64	8·32	10·85	11·02	9·78	9·72	64·6	63·9	71·1	72·0	65·7	67·5
N	7·42	6·47	7·10	7·76	7·64	7·28	62·5	55·5	59·8	62·2	64·9	61·0
A	6·87	7·09	7·79	8·81	8·10	7·73	60·3	59·6	61·4	65·6	63·5	62·1
AC	5·70	6·30	6·85	7·08	6·74	6·53	52·1	53·3	57·8	60·5	58·1	56·4
C	7·29	7·92	7·95	8·26	7·76	7·84	61·4	60·7	61·9	63·8	64·4	62·4
Mean	7·18	7·22	8·11	8·59	8·00	7·82	60·2	58·6	62·4	64·8	63·3	61·9
	REDUCING SUGAR											
	Per cent. of fresh weight						Per cent. of dry matter					
O	0·34	0·29	0·21	0·23	0·23	0·26	2·5	2·2	1·4	1·5	1·5	1·8
N	0·38	0·42	0·42	0·26	0·23	0·34	3·2	3·6	3·5	2·1	2·0	2·9
A	0·25	0·25	0·17	0·25	0·27	0·24	2·2	2·1	1·3	1·9	2·1	1·9
AC	0·23	0·24	0·18	0·26	0·25	0·23	2·1	2·0	1·5	2·2	2·2	2·0
C	0·33	0·28	0·25	0·44	0·32	0·32	2·8	2·1	1·9	3·4	2·7	2·6
Mean	0·31	0·30	0·25	0·29	0·26	0·28	2·6	2·4	1·9	2·2	2·1	2·2
	Ratio Sucrose : Reducing sugars						Total sugar (cwt. p.a.)					
O	25·8	29·0	50·8	48·0	43·8	39·5	38·3	41·3	17·8	13·4	14·1	25·0
N	19·5	15·4	17·1	29·6	32·4	22·8	54·5	47·9	35·5	40·3	44·4	44·5
A	27·4	28·4	47·2	34·5	30·2	33·5	34·2	45·6	16·0	40·1	36·5	34·5
AC	24·8	26·6	38·5	27·5	26·4	28·8	29·2	45·5	16·4	46·9	48·7	37·3
C	21·9	28·9	32·6	18·8	23·9	25·2	40·4	51·8	19·6	43·8	45·8	40·3
Mean	23·9	25·7	37·2	31·7	31·3	30·0	39·3	46·4	21·1	36·9	37·9	36·3

• O = unmanured; N = nitrate of soda; A = sulphate of ammonia; AC = rape-cake and sulphate of ammonia; C = rape-cake.

relatively smaller, and the potash effect greater. Evidently the effects of nitrogenous fertilizers and the mixture of sodium and magnesium salts on sucrose as per cent. of fresh weight are only partly attributable to the reduction of dry-matter content which they caused.

The responses of reducing-sugar content to manurial treatment were not so clear-cut as those of sucrose-content. There is evidence that deficiency of potash, as on plots 5–AC and 5–A, lowered the reducing-sugar content. Sodium and magnesium salts, given in addition to potash,

had a variable effect; on the average they slightly depressed reducing sugar as per cent. of fresh weight, but had no appreciable effect on reducing sugar as per cent. of dry matter. The effects of the nitrogenous fertilizers were not consistent; nitrate of soda and rape-cake produced an increase, but sulphate of ammonia applied alone or together with rape-cake had little effect. Farmyard manure markedly increased the reducing-sugar content.

The relative magnitudes of the manurial effects on sucrose and reducing-sugar are best shown by the changes in their ratio. Plot 5–O, which received phosphate only, had the highest sucrose: reducing-sugar ratio. There is an indication that phosphate and potash applied together in the presence of farmyard manure increased the ratio, but all other manurial treatments tended to reduce it. For sulphate of ammonia, this reduction is almost entirely the result of the fall of sucrose-content; for nitrate of soda, rape-cake, and farmyard manure it is the combined effect of a fall of sucrose-content and a rise of reducing-sugar content; for potash, it is due to a relatively greater increase of reducing-sugar content than of sucrose-content. The mixture of sodium and magnesium salts had only a very small effect on the ratio.

Lawes and Gilbert assumed that the reduction of sugar-content caused by nitrogenous fertilizers was an indication of delayed maturation. They say that 'the lower the nitrogenous manuring, the riper is the crop, and with this there is the higher percentage of sugar'. Hall, similarly, states that 'the use of ammonium salts promotes an earlier maturity than does nitrate of soda; this is seen in the generally higher quotient of purity (sucrose as per cent. of dry matter) of the A series as compared with the N series'. He accounts for the changes in the sucrose: reducing-sugar ratio in the same way; a fall in the ratio is assumed to be associated with delayed maturity. Neither Lawes and Gilbert nor Hall give a precise definition of the meaning which they attached to the terms ripeness or maturity. Apparently they assessed the degree of maturity mainly by the appearance of the leaves at harvest, and particularly by the development of a yellow coloration. It is doubtful whether the mangold crop can be said to ripen in any strict sense, for there is no well-defined transition from a phase of active growth to a phase of dormancy, but rather a steady diminution of growth as autumn conditions become progressively less favourable. The orange-yellow coloration of the leaves in autumn is not a reliable criterion of senescence; very often it is caused by infection with beet Yellows virus. Any interpretation of the variations in sugar-content on the basis of differential maturity is therefore of doubtful validity, and does not help to explain their physiological origin and significance. To do this, a fuller knowledge of the effects of the nutrient elements on the carbohydrate metabolism of the mangold is required.

The effects of fertilizer treatment on sugar-content were small relative to the effects on the weight of roots. Consequently, the variations in the yield of sugar per acre follow fairly closely those of the yield of roots. Thus, although nitrogenous fertilizers depressed the sugar-content, they greatly increased the yield of sugar per acre. The yields of sugar shown in Table 4 probably differ considerably from the means for the whole

period of the Barnfield experiment. The yields of roots in 1900 and 1902 were much above the average, and those of the nitrate of soda plots (series N) were particularly high. Plot 1–AC, on the other hand, had an abnormally low yield relative to the other plots. It is probable that on the average of the whole period of the experiment, series AC with the heaviest dressing of nitrogen gave a higher yield of sugar per acre than the other series; this result was in fact found in the earlier period, 1877–80, for which data on sugar-content exist. Farmyard manure and potash also produced large increases in the yield of sugar per acre, but the effect of the mixture of sodium and magnesium salts was small.

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[References to the literature will be given at the end of Part IV.]

THE ROTHAMSTED EXPERIMENTS ON MANGOLDS, 1876–1940

PART IV: THE COMPOSITION OF THE MANGOLDS GROWN ON BARNFIELD; (ii) THE NITROGEN-CONTENT OF LEAVES AND ROOTS

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TABLE 5 shows the mean nitrogen-contents as per cent. of dry matter of the leaves and roots at harvest of the mangolds grown on Barnfield. For strips 4, 5, and 6 a fairly long series of determinations exists, but for strips 1 and 2 the analyses were done less frequently. Means for strips 4, 5, and 6, taken over the same years as those for strips 1 and 2, differ little from the means for the longer period of years given in Table 5.

TABLE 5. *Mean Nitrogen-content of Mangolds as Per Cent. of Dry Matter, Barnfield*

	Strip					
Series	*1* FYM	*2* FYM+P	*5* P	*6* PK	*4* PKNaMg	*Mean of 4, 5, and 6*
	LEAVES					
O	2·99	3·11	2·60	2·60	2·64	2·62
N	3·43	3·42	3·18	3·07	2·90	3·05
A	3·75*	3·44	3·47	2·78	2·74	3·00
AC	4·28	3·63*	3·99	3·12	3·08	3·40
C	3·71	3·32	3·71	2·86	2·82	3·13
Mean	3·63	3·38	3·39	2·89	2·84	3·04
	ROOTS					
O	1·31	1·38	0·93	0·95	0·94	0·94
N	1·88	1·88	1·61	1·46	1·45	1·51
A	1·90	1·86	1·62	1·23	1·27	1·37
AC	2·08	2·05	1·94	1·65	1·69	1·76
C	1·72	1·72	1·64	1·35	1·31	1·43
Mean	1·78	1·78	1·55	1·33	1·33	1·40

Years averaged:

Leaves: Strips 1 and 2: 5 years, 1896, 1898, 1899, 1900, 1902.
Strips 4, 5, 6: 14 years 1887–1902, excluding 1895 and 1901.

Roots: Strips 1 and 2: 10 years, 1878–82 and 1896–1900.
Strips 4, 5, 6: 21 years, 1878–1900, excluding 1885 and 1895.

* 4 years only, 1900 omitted.

The mean nitrogen-content of the leaves was about twice that of the roots. As might be expected, nitrogenous fertilizers increased the nitrogen-content, and the effect increased with increase in the rate of application

(comparison of series AC with series N, A, and C). Potash reduced the nitrogen-content.

The other manurial treatments had smaller and less consistent effects.

The mixture of sodium and magnesium salts, applied in addition to potash, slightly reduced the nitrogen-content of the leaves but did not appreciably affect that of the roots. Both farmyard manure and phosphate decreased the nitrogen-content of the leaves, except when no nitrogenous fertilizer was given. Farmyard manure consistently increased the nitrogen-content of the roots, whilst phosphate had no effect.

Comparison of Tables 4 (p. 54 of Pt. IV (i)) and 5 shows an inverse correlation between the sucrose- and nitrogen-contents of the root as per cent. of dry matter; high sugar-content was associated with low nitrogen-content. This correlation arises partly from the necessity that, if the proportion of one constituent rises, that of the others must fall. However, the variation of nitrogen-content with fertilizer treatment cannot be accounted for entirely by the concomitant changes in sugar-content, for when nitrogen-content is expressed as per cent. of the non-sugar constituents of dry matter the fertilizer effects still persist.

Table 6 gives the mean nitrogen-contents of the roots as per cent. of residual dry matter (dry matter less sucrose) for five seasons in which both nitrogen- and sugar-contents were determined.

TABLE 6. *Nitrogen-content as Per Cent. of Residual Dry Matter of Mangold Roots, Barnfield.* (*Mean of 1878–80, 1898, and 1900*)

	Strip					
Series	*1* FYM	*2* FYM+P	*5* P	*6* PK	*4* PKNaMg	*Mean*
O	2·92	3·25	2·33	2·38	2·09	2·59
N	3·62	3·65	3·19	3·28	3·29	3·41
A	4·00	3·72	3·58	2·82	2·67	3·36
AC	4·19	4·25	4·32	3·93	3·33	4·00
C	3·72	3·67	3·76	2·97	2·78	3·38
Mean	3·69	3·71	3·44	3·08	2·83	3·35

Nitrogenous fertilizers and farmyard manure increased the nitrogen-content as per cent. of residual dry matter; potash decreased it. The mixture of sodium and magnesium salts also caused a depression, which was not apparent in Table 5, where nitrogen-content was expressed as per cent. of total dry matter.

The mean nitrogen-contents of leaves and roots in lb. per acre are shown in Table 7. They vary widely with manurial treatment, ranging from 6 to 40 lb. in the leaves and from 12 to 120 lb. in the roots.

Nitrogenous fertilizers greatly increased the weight of nitrogen per acre in both leaves and roots, sulphate of ammonia having a smaller effect than nitrate of soda or rape-cake. Potash, and the mixture of sodium and magnesium salts, increased the weight of nitrogen in the roots, but slightly reduced that in the leaves. Farmyard manure, which supplies both nitrogen and potash, produced effects intermediate between those of the

nitrogenous and potassic fertilizers; it greatly increased the weight of nitrogen in the roots, but caused only a small increase in that of the leaves.

The relation of the distribution of nitrogen between leaves and roots is shown by the ratios of N in roots: total N in crop (Table 7). On the plots which received farmyard manure, or both nitrogenous and potassic fertilizer, about 75 per cent. of the total nitrogen in the crop was contained in the roots, but where the nitrogenous fertilizer was omitted, or where no potassium or sodium salts (including nitrate of soda) were given, only 60 to 65 per cent. of the total nitrogen was present in the roots.

TABLE 7. *Nitrogen-content, in lb. per Acre, of Mangolds, Barnfield*

	Strip					
Series	*1* FYM	*2* FYM+P	*5* P	*6* PK	*4* PKNaMg	*Mean of 4, 5, 6*
			LEAVES			
O	18·4	17·8	7·3	6·2	6·4	6·6
N	29·0	30·5	25·4	22·6	24·1	24·0
A	32·6*	34·0	24·0	18·7	16·2	19·7
AC	34·5†	41·0*	34·5	37·7	33·0	35·0
C	33·7	29·6	29·3	21·8	20·9	24·0
Mean	29·6	30·6	24·1	21·4	20·1	21·9
			ROOTS			
O	56·4	62·7	13·4	12·1	14·1	13·2
N	105·8	112·2	61·3	57·8	66·0	61·7
A	93·3	105·4	34·8	48·2	49·6	44·2
AC	112·2	128·6	53·0	97·0	102·2	84·1
C	97·5	103·0	50·5	68·0	68·8	62·5
Mean	93·0	102·4	42·6	56·6	60·1	53·1
			RATIO N IN ROOTS : TOTAL N IN CROP			
O	0·75	0·78	0·65	0·66	0·69	..
N	0·78	0·79	0·71	0·72	0·73	..
A	0·74	0·76	0·59	0·72	0·75	..
AC	0·76	0·76	0·61	0·72	0·76	..
C	0·74	0·77	0·63	0·73	0·75	..

Years averaged:
Leaves: Strips 1 and 2: 4 years, 1898–1900 and 1902.
Strips 4, 5, and 6: 14 years, 1887–1902, excluding 1895 and 1901.
Roots: Strips 1 and 2: 10 years, 1878–82, and 1896–1900.
Strips 4, 5, and 6: 21 years, 1878–1900, excluding 1885 and 1895.
* 3 years only: 1900 omitted. † 3 years only: 1902 omitted.

The nitrogen-content in lb. per acre of mangolds grown continuously on Barnfield without nitrogenous fertilizer, but with potash and phosphate, was remarkably close to that of other crops grown in similar conditions at Rothamsted. This is shown by the following results given by Lawes and Gilbert [2]:

	Total N *in crop, lb. per acre*
Wheat, Broadbalk field, 1864–75 . . .	17·2
Barley, Hoosfield, 1864–75	18·8
Swedes, Barnfield, 1856–70	18·5
Sugar-beet, Barnfield, 1871–5 . . .	14·7
Mangolds, Barnfield, 1876–85 . . .	14·0

Analyses made in 1879 and 1880 [2] showed that about 10 per cent. of the nitrogen in the root is present in the form of nitrate; the remainder is almost equally divided between protein and non-protein fractions. The data are inadequate to admit of any discussion of the variations of these proportions, and no subsequent determination of the nitrogen distribution has been made.

Recovery of added nitrogen.—The recovery in a crop of a nutrient added in a fertilizer is usually estimated from the difference between the nutrient contents of crops grown with and without the fertilizer on similar soil. This method will give an accurate measure of the amount of the nutrient taken up by the crop from the fertilizer, only if the amount taken up from the soil is the same in the presence of the fertilizer as in its absence. There is reason to suppose that this is not true of the uptake of nitrogen from the soil of plots with and without nitrogenous fertilizer on Barnfield. Even before the cropping with mangolds began, the nitrogen-content of the soil of the plots which receive no nitrogen was already below that of the plots to which nitrogenous fertilizers are given (see [4] Table 4, Part III). Also, as the crops on the nitrogen-treated plots are very much heavier than on the no-nitrogen plots, it is probable that they have a more extensive root-system, and so draw their nutrient supply from a larger volume of soil. For both these reasons it is probable that the uptake of nitrogen from the original supply in the soil has been greater on the nitrogen-treated plots than on the no-nitrogen plots. The conventional method of calculation is therefore likely to overestimate the recovery in the crop of nitrogen applied in the fertilizers.

Hall [5] considered it unlikely that the nitrogen-content of the soil of the plots of Barnfield fertilized with nitrate of soda or sulphate of ammonia had diminished since the beginning of the experiment, whilst it is known that the soil of the farmyard-manure plots has become richer in nitrogen. He argued that, if the soil has suffered no loss of nitrogen, the whole of the nitrogen removed in the crop on these plots must have been derived from the manure, and calculated the nitrogen-recovery on this assumption. This argument is fallacious, for constancy or increase in the nitrogen-content of the soil is not evidence that none of the nitrogen originally present was removed in the crop, but merely implies that the losses were balanced or exceeded by residues left from the manure. Hall's method of calculation gives even higher percentage recoveries of added nitrogen than the conventional method, which, as has already been shown, itself probably gives too high values.

A further complication is that the mangold tops are ploughed in, and not carted off, so that the nitrogen which they contain is returned to the soil, and may become available in part to the succeeding crop.

In view of these considerations the nitrogen contained in the tops has been excluded from the estimates of nitrogen-recovery, and these have been calculated from the differences in nitrogen-content of the roots (Table 7) grown on plots with and without added nitrogenous fertilizer. The nitrogen-recovery from farmyard manure was determined similarly, from the difference in nitrogen-content of the roots from plots receiving the same mineral fertilizers with and without farmyard manure (i.e.

difference between plots 2 and 5 of each series). The recovery is expressed as per cent. of the weight of nitrogen supplied in the fertilizer or farmyard manure (Table 8). It must be borne in mind that the validity of these figures is doubtful, because of the uncertainty as to the amount of nitrogen taken up by the crop from the soil.

TABLE 8. (*a*) *Per Cent. of Nitrogen, added in Nitrogenous Fertilizers, recovered in Mangold Roots, Barnfield**

	Nitrogenous fertilizer applied in presence of:					
	FYM	FYM+P	P	PK	PKNaMg	
	Strip					
Nitrogen applied as	*1*	*2*	*5*	*6*	*4*	*Mean of 4, 5 and 6*
Nitrate of soda . .	57·4	57·6	55·7	53·1	60·3	56·4
Sulphate of ammonia .	42·9	49·7	24·9	42·0	41·3	36·0
Sulphate of ammonia and rape-cake	30·3	35·8	21·5	46·1	47·9	38·5
Rape-cake . . .	41·9	41·1	37·9	57·0	55·8	50·3

(*b*) *Per Cent. of Nitrogen, added in Farmyard Manure, recovered in Mangold Roots, Barnfield*†

In presence of phosphate and:					
No N	*Nitrate of soda*	*Sulphate of ammonia*	*Sulphate of ammonia and rape-cake*	*Rape-cake*	*Mean*
24·8	24·6	34·6	38·2	28·4	30·1

* 21 years, 1878–1900, excluding 1885 and 1895.
† 10 years, 1878–82 and 1896–1900.

In the presence of the complete mineral-fertilizer dressing 60 per cent. of the nitrogen given as nitrate of soda was recovered in the roots. The other nitrogenous fertilizers were assimilated less efficiently; only 56 per cent. of the nitrogen from rape-cake, and 41 per cent. of that from sulphate of ammonia was recovered. The recovery from the mixture of sulphate of ammonia and rape-cake, 48 per cent., was almost exactly the mean of the recoveries from the two fertilizers given separately, showing that, in presence of adequate potash and soda, the ability of the crop to take up nitrogen did not decline with increase in the rate of nitrogen supply.

The most obvious feature of Table 8 (*a*) is the low recovery of nitrogen from sulphate of ammonia and rape-cake, on the plots which received no potash or soda and magnesia. The omission of these nutrients had little effect on the recovery from nitrate of soda, presumably because the nitrate of soda itself supplies sodium. In these conditions the recovery of added nitrogen declined with increase in the rate of application (cf. plots of strip 5 receiving sulphate of ammonia and rape-cake separately and together), but the presence of farmyard manure increased the recovery from the nitrogenous fertilizers, presumably because the farmyard manure supplied potash as well as nitrogen.

The average recovery of nitrogen from that supplied in the farmyard manure (Table 8(*b*)) was 30 per cent. It was greater where sulphate of ammonia or rape-cake were given than in the presence of nitrate of soda. These values for farmyard manure are determined in the absence of potash or soda, and the apparent high recovery on the sulphate of ammonia and rape-cake plots is attributable to an increased utilization of the nitrogen given in these fertilizers, brought about by the supply of potash in the farmyard manure.

The recovery of nitrogen in the mangold crop on Barnfield was greater than in wheat and barley grown continuously in comparable experiments at Rothamsted and Woburn (Table 9).

TABLE 9. *Percentage Recovery of Added Nitrogen in Continuously Grown Crops*

	Nitrate of soda	*Sulphate of ammonia*	*Farmyard manure*
Mangolds. Barnfield, Rothamsted . .	60	41	25
Wheat. Broadbalk, Rothamsted [6] . .	..	35	15
Barley. Hoosfield, Rothamsted [7] . .	43	38	18
Barley. Stackyard field, Woburn [7] . .	40	..	33

The only exception is that barley at Woburn recovered a slightly higher proportion of the nitrogen applied in farmyard manure, perhaps because the dressing of farmyard manure was only half that given on Barnfield. If the comparison could be made with continuously grown mangolds in conditions where the tops were removed and not ploughed back, it is probable that the difference between the nitrogen recoveries by mangolds and cereals would be greatly increased.

Seasonal variation of nitrogen-content.—The nitrogen-content of the mangolds grown on Barnfield varied widely from season to season; for example, on plot 4–AC, in the years for which records are available, it ranged from 2·31 to 3·95 per cent. of dry matter in the leaves and from 0·90 to 2·70 per cent. in the roots.

The following account of the seasonal variation deals only with plots 4, 5, and 6 of each series, for analyses were made very infrequently on the produce of strips 1 and 2. To reduce the labour of computation the statistical examination has been carried out either on the annual means of plots 4, 5, and 6 for each series, to show the effect of nitrogenous fertilizers, or on the annual means of all series for strips 4, 5, and 6, to show the effects of potash and soda, and not on the data for individual plots.

The magnitude of the seasonal variation on the different strips and series can be compared by means of the Standard Errors for a single year shown in Table 10.

In the 13 years when analyses were made on both leaves and roots the nitrogen-content of the leaves varied less than that of the roots, but the Standard Errors for the roots in this period were somewhat greater than in the longer period of 21 years between 1878 and 1900. Fertilizer treatment had little effect on the seasonal variation.

TABLE 10. *Standard Errors, for a Single Year, of Nitrogen as Per Cent. of Dry Matter in Mangolds, Barnfield*

Series	Mean of strips 4, 5, and 6				
	O	N	A	AC	C
Leaves, 13 years*	0·327	0·399	0·297	0·302	0·346
Roots, 13 years*	0·448	0·447	0·518	0·420	0·422
Roots, 21 years†	0·359	0·390	0·419	0·350	0·363

Strip	Mean of all series		
	4	5	6
Leaves, 13 years*	0·335	0·291	0·254
Roots, 13 years*	0·489	0·367	0·416
Roots, 21 years†	0·408	0·306	0·354

* 1887 to 1900, omitting 1895.
† 1878 to 1900, omitting 1885 and 1895.

It was obvious from inspection that the nitrogen-contents of leaf and root were positively correlated; high values of nitrogen-content occurred in leaf and root in the same seasons, and similarly for low values. Table 11 shows that the correlation was very close for series O, A, and C; it was lower for series N, and on series AC it was still smaller and not significant.

TABLE 11. *Correlation between Nitrogen-contents as Per Cent. of Dry Matter of Leaf and Root in Different Seasons, Barnfield*

Series	Means of strips 4, 5 and 6				
	O	N	A	AC	C
Correlation coefficient	0·874	0·624	0·866	0·494	0·891
Variance accounted for, per cent.	74	33	75	18	78

Strip	Means of all series		
	4	5	6
Correlation coefficient	0·809	0·729	0·702
Variance accounted for, per cent.	62	49	44

When the nitrogen supply was high, as on series AC, the nitrogen-contents of leaf and root were less dependent on each other than when the supply was more restricted. Presumably, as the nitrogen supply increases, other factors, which may differ for leaf and root, play a greater part in determining nitrogen-content. But no explanation can be offered for the low correlation on series N. It cannot be attributed to the sodium supplied by nitrate of soda, for the correlation coefficient for strip 4, which received sodium chloride, was greater than those for strips 5 and 6 which did not.

A detailed statistical analysis of the relation of seasonal variation in nitrogen-content to weather conditions, or to other attributes of the crop, has not been attempted, because of the short period covered by the

records. It has, however, been shown that the nitrogen-content of the roots was dependent on the yield of roots and on rainfall during the early part of the growing season.

Table 12 gives the partial regression coefficients of nitrogen-content as per cent. of dry matter and in lb. per acre on yield, and on rainfall during the four months, May to August, calculated for the means of plots 4, 5, and 6 for each series. A preliminary investigation by calculating the mean nitrogen per cent. for groups of years of high, medium, and low rainfall in the three bi-monthly periods, May–June, July–August, September–October independently, had shown that rainfall in the last period had little effect. When partial regression coefficients of nitrogen-content on rainfall during the bi-monthly periods, May–June and July–August, were calculated separately, it was found that in no case did they differ significantly. The correlation between yield and May–August rainfall was small, so that the regression coefficients on yield alone differed little from the partial regressions shown in Table 12.

TABLE 12. *Regression Coefficients of Nitrogen-content of Roots on Yield of Roots in Tons per Acre, and May–August Rainfall in Inches. Barnfield, 1878–1900, omitting 1885 and 1895*

Mean rainfall 9·97 in.

Mean of strips 4, 5, 6 on series	*Mean N content*	*Mean yield, tons per acre*	*Regression coefficients of N content on:*		*Variance accounted for, per cent.*
			Yield	*May–August rainfall*	
			Nitrogen as per cent. of dry matter		
O	0·94	4·76	−0·1665±0·233	−0·0319±0·0130	72
N	1·51	16·18	−0·0311±0·0073	−0·0548±0·0166	62
A	1·37	12·08	−0·0387±0·0110	−0·0607±0·0193	57
AC	1·76	18·59	−0·0254±0·0073	−0·0498±0·0168	51
C	1·43	16·29	−0·0411±0·0073	−0·0531±0·0140	68
			Nitrogen, lb. per acre		
O	13·2	4·76	1·51±0·254	−0·210±0·142	66
N	61·7	16·18	3·30±0·349	−0·638±0·792	82
A	44·2	12·08	2·99±0·381	−0·672±0·670	75
AC	84·1	18·59	3·24±0·360	−1·610±0·830	80
C	62·5	16·29	2·30±0·240	−1·537±0·457	84

The regression coefficients of nitrogen-content on yield were all highly significant. They show that, on all series, nitrogen as per cent. of dry matter decreased, and nitrogen-uptake in lb. per acre increased, as yield increased. On series O, where no nitrogenous fertilizer was given, variation of yield was accompanied by a greater change in nitrogen per cent. and a smaller change in nitrogen-uptake in lb. per acre, than on the other series which received nitrogenous fertilizers.

The relation between yield and nitrogen-content is obviously one of great complexity. Nitrogen-uptake can, in one sense, be regarded as one of the factors which determine yield. On the other hand, in so far as yield is dependent on factors such as weather conditions, acting independently

of nitrogen supply, yield may be regarded as a determinant of nitrogen-uptake. The regressions of nitrogen-content on yield do not represent an effect of yield, in the ordinary sense of the word; they represent, rather, an interrelation between two end-products of the same complex series of causes. Further, the quantitative relations between yield, nitrogen-uptake, and nitrogen per cent. are not adequately expressed by the linear regressions shown in Table 12. If, for example, the relation between yield and nitrogen-uptake is a linear one, that between yield and nitrogen per cent. cannot also be linear. The results may be interpreted qualitatively as showing that when the nitrogen supply is restricted, as on series O, the nitrogen-uptake in a large crop does not greatly exceed that in a small crop, and the nitrogen per cent. therefore varies widely with yield; when a liberal supply of nitrogen is given, however, the amount of nitrogen absorbed is greatly dependent on the size of the plants, and the variation of nitrogen per cent. with yield is small.

The regression coefficients of nitrogen-content as per cent. of dry matter on May–August rainfall were all highly significant. They show that one additional inch of rainfall above the average in May–August depressed the nitrogen-content by about 0·05 per cent. of dry matter, except on series O, where the effect was somewhat smaller, amounting to only 0·03 per cent. As they are partial regressions, representing the effect of rainfall when yield is held constant, they imply that additional rainfall above the average also reduced the total uptake of nitrogen by the roots. The regression coefficients of nitrogen-content in lb. per acre on May–August rainfall were, in fact, all negative but only that for series C was significant. The coefficient for series AC approached significance, but those for series O, N, and A were of about the same magnitude as their standard errors. The results suggest that the adverse effect of rainfall on nitrogen-uptake was particularly great where nitrogen was applied in the form of rape-cake (series AC and C).

The lack of clear-cut rainfall effects on nitrogen-content in lb. per acre, although the results for nitrogen per cent. suggest that these effects existed, is not easy to explain. The nitrogen-content in lb. per acre cannot be estimated independently of yield, but must be calculated from the product of yield, dry matter as per cent. of fresh weight, and nitrogen-content as per cent. of dry matter. It is, therefore, susceptible to errors involved in all three of these determinations, and is likely to show a spuriously high correlation with yield. Both these effects may have obscured the regressions on rainfall.

There is little point in discussing the nature of the effect of rainfall on nitrogen-uptake, in view of the uncertainty as to its existence except on series C. But it may be noted that as there is little or no drainage through a cropped soil in the months May–August, especially in the later part of the period, it is unlikely that additional rainfall above the average can have reduced nitrogen-uptake by leaching of nitrate to parts of the soil beyond the range of the roots.

The mineral-content of leaves and roots.—Analyses of the mineral constituents of the ash of leaves and roots of mangolds grown on Barnfield were made on bulked samples for six seasons, 1878–83, of the

produce of plots 5 and 6 of each series. Some of the results were quoted by Lawes and Gilbert [2]; they are shown in greater detail in Table 13.

TABLE 13. *Mineral-content of Mangolds, Barnfield. (Mean of 6 Years, 1878–83)*

	K_2O		Na_2O		CaO		MgO		P_2O_5	
*Strip**	5	6	5	6	5	6	5	6	5	6
	Per cent. of dry matter									
Series	LEAVES									
O	2·26	5·15	4·38	2·69	2·94	2·78	0·56	0·52	0·68	0·69
N	0·95	1·92	6·80	6·12	1·84	2·08	0·53	0·45	0·72	0·65
A	1·21	4·08	3·16	3·25	4·21	3·12	0·95	0·82	0·72	0·64
AC	1·10	3·48	2·11	2·56	4·75	4·25	1·07	1·05	0·75	0·60
C	1·19	3·99	2·62	3·11	3·97	3·06	0·95	0·80	0·70	0·61
	ROOTS									
O	1·88	2·70	0·63	0·25	0·31	0·28	0·16	0·16	0·66	0·66
N	1·10	2·40	2·50	1·29	0·24	0·24	0·14	0·14	0·67	0·62
A	1·42	3·15	1·05	0·44	0·44	0·29	0·17	0·17	0·64	0·60
AC	1·64	3·23	0·85	0·49	0·48	0·34	0·21	0·19	0·62	0·58
C	1·52	2·98	0·77	0·41	0·39	0·29	0·19	0·18	0·65	0·63
	Lb. per acre									
	LEAVES									
O	4·7	10·2	9·2	5·3	6·2	5·5	1·2	1·0	1·4	1·4
N	6·5	12·0	46·5	38·2	12·5	12·9	3·6	2·8	4·9	4·0
A	8·6	24·6	22·6	19·6	30·1	18·8	6·8	4·9	5·1	3·9
AC	10·7	40·2	20·6	29·6	46·4	49·0	10·5	12·1	7·3	6·9
C	9·3	25·2	20·5	19·7	31·1	19·4	7·4	5·1	5·5	3·8
	ROOTS									
O	28·4	36·3	9·5	3·4	4·7	3·8	2·5	2·2	10·0	8·9
N	46·5	113·0	106·3	60·9	10·3	11·3	6·0	6·7	28·3	29·4
A	36·6	136·8	27·0	18·9	11·2	12·6	4·5	7·4	16·4	25·9
AC	53·4	203·3	27·8	30·8	15·6	21·4	6·9	12·0	20·3	36·5
C	56·0	154·2	28·4	21·4	14·4	14·9	7·2	9·3	24·1	32·8
	WHOLE PLANT									
O	33·1	46·5	18·7	8·7	10·9	9·3	3·7	3·2	11·4	10·3
N	53·0	125·0	152·8	99·0	22·8	24·2	9·6	9·5	33·3	33·4
A	45·3	161·4	49·6	38·6	41·3	31·4	11·2	12·3	21·5	29·8
AC	64·1	243·5	48·4	60·4	62·0	70·5	17·4	24·0	27·6	43·5
C	65·3	179·4	48·9	41·0	45·5	34·3	14·6	14·3	29·6	36·7

* Strip 5 receives phosphate, strip 6 phosphate and potash.

The data show the effects of nitrogenous and potassic fertilizers, but give no information on the changes in mineral-content produced by farmyard manure, phosphate, or the mixture of sodium and magnesium salts.

Potassium.—The proportions of potash in the dry matter of leaves and roots did not differ greatly. In both leaves and roots potash per cent. was increased by the application of sulphate of potash, whilst nitrogenous fertilizers usually caused a decrease. The potash-content of the leaves varied more widely with fertilizer treatment than that of the roots.

The weight of potash per acre in leaves and roots was increased only

slightly by nitrogenous and potassic fertilizers applied separately, but when both were applied the increase in potash-uptake was very large.

The most interesting feature of the data lies in the difference between the effects of nitrate of soda and the other nitrogenous fertilizers. The plants on the nitrate of soda plots had a lower content of potash as per cent. of dry matter, especially in the leaves, than those on the plots which received sulphate of ammonia or rape-cake. The same is true of the weight of potash per acre in leaves and roots, except that on strip 5, in the absence of potassic fertilizer, the roots had a slightly higher potash-content on the nitrate of soda plots than on the sulphate of ammonia plots. Thus, on strip 5 at a low level of potash supply, nitrate of soda produced much larger crops than the other nitrogenous fertilizers without increasing the uptake of potash, but on strip 6 where the potash supply was liberal, nitrate of soda produced yields similar to those given by the other nitrogenous fertilizers, but with a much lower uptake of potash. This effect of nitrate of soda in restricting potash uptake, is readily seen when the recoveries of added potash in the presence of the different nitrogenous fertilizers are compared (Table 14). The recoveries were calculated for the roots only, since the tops were ploughed back, and it has been assumed that the dressing of 500 lb. of sulphate of potash per acre, applied on strip 6, supplied 250 lb. K_2O.

TABLE 14. *Percentage of Added Potash recovered in Mangold Roots, Barnfield, 1878–83*

In presence of:	*No nitrogen*	*Nitrate of soda*	*Sulphate of ammonia*	*Sulphate of ammonia and rape-cake*	*Rape-cake*
Series:	O	N	A	AC	C
	3·2	26·6	40·0	60·0	39·3

Where nitrogen was given as nitrate of soda, less than 30 per cent. of the added potash was taken up in the roots, as compared with 40 per cent. when equivalent nitrogen was applied as sulphate of ammonia or rape-cake. Table 14 also shows that the uptake of added potash increases with increase in the amount of nitrogen supplied (comparison of series AC with series A and C), and that in conditions of nitrogen deficiency (series O) the utilization of added potash is very inefficient.

Table 13 shows that rape-cake caused a greater increase in the potash-content of the crop than sulphate of ammonia. The extra potash presumably came from that supplied in the rape-cake. There is no record of the composition of the rape-cake used in 1878–93, but the potash-content of the material used in recent years has varied from 1 to 1·5 per cent. of fresh weight, so that the 2,000 lb. dressing applied per acre contained from 20 to 30 lb. of K_2O. The difference between the potash-contents of the roots of the crops grown on the rape-cake and sulphate of ammonia plots of strip 6 was 17·4 lb. per acre. Hence, the recovery in the roots of the potash supplied in the rape-cake lay between 58 and 87

per cent., depending on the value assumed for the potash-content of the rape-cake dressing within the range from 30 to 20 lb. per acre. Even the lower figure is surprisingly high, considering that strip 6 had a liberal supply of potash in the form of sulphate. The rape-cake dressing contained about 100 lb. of nitrogen, compared with 86 lb. in the sulphate of ammonia; as it has already been shown that the recovery of potash increases with increase in the nitrogen supply, it is probable that there was a greater recovery of potash from the sulphate of potash dressing and from the soil on the rape-cake plots than on the sulphate of ammonia plots, and this would tend to increase the apparent recovery of potash from the rape-cake. Nevertheless, the results indicate that the potash present in rape-cake is in a form readily available to plants, for the fraction of it recovered in the crop was of the same order as that of potash supplied in the form of sulphate.

Sodium.—Table 13 shows that the sodium-content, as per cent. of dry matter, of the leaves was very much greater than that of the roots. Consequently, the total weight of soda in the crop was almost equally divided between leaves and roots, in spite of the much greater yield of roots than of leaves. This contrasts sharply with the distribution of potash, of which by far the larger fraction was present in the roots.

The addition of sulphate of potash approximately halved the soda-content as per cent. of dry matter of the roots, but had little effect on that of the leaves. The total uptake of soda in the crop was almost the same, whether sulphate of potash was given or not. Sulphate of ammonia and rape-cake slightly increased the percentage of soda in the dry matter of the roots but did not much affect that of the leaves; they greatly increased the weight of soda per acre in both leaves and roots.

The crops on the nitrate of soda plots had a much greater soda-content than others, which is not surprising, for these were the only crops which had a supply of sodium additional to that present in the soil. The soda-contents, as per cent. of dry matter of leaves and roots on the nitrate of soda plots, were about twice those of the crops grown with sulphate of ammonia. The nitrate of soda dressing of 550 lb. per acre supplied approximately 195 lb. Na_2O. An estimate of the proportion recovered in the crop can be made from the difference in the weight of soda present in the roots grown on the nitrate of soda plots, and those on the sulphate of ammonia plots; in the absence of added potash it amounted to 41 per cent. and, where potash was given, to 22 per cent. These values agree closely with the percentage recoveries of potash, applied in the absence or presence of sodium (Table 14). Apparently the mangold plant absorbs potassium and sodium ions with nearly equal facility. On plot 6–N, for example, which received annually 250 lb. K_2O and 195 lb. Na_2O per acre, about a quarter of both potash and soda was recovered in the roots, and if the leaves are taken into account, the recoveries of potash and soda are in even closer agreement. There is no evidence of preferential absorption of potash or soda.

Calcium.—Like sodium, calcium (Table 13) was present in much higher concentration in the leaves than in the roots. The content of CaO per cent. of dry matter in both leaves and roots was slightly reduced by

addition of sulphate of potash, and was increased by nitrogenous fertilizers, except nitrate of soda, which caused a decrease.

The weight of CaO per acre was much greater in the leaves than in the roots, especially on the sulphate of ammonia and rape-cake plots. As the leaves were returned to the soil each season, the weight of CaO removed in the crop annually was trivial compared with the losses which are known to occur by leaching ; it amounted only to 21 lb. per acre at its maximum on plot 6–AC. The total uptake of calcium in the crop was increased by nitrogenous fertilizers.

Magnesium.—Magnesium (Table 13) was present in both leaves and roots in smaller concentration than the other bases. The magnesia-content per cent. of the dry matter in the root showed little variation with fertilizer treatment; in the leaf it increased with addition of nitrogenous fertilizers, except nitrate of soda, but was scarcely affected by addition of sulphate of potash.

The total weight of magnesia per acre, like that of soda, was roughly equally divided between leaves and roots. It was greater where nitrogenous fertilizer was applied.

Total base-content.—The total base-content of the leaves as per cent. of dry matter was remarkably constant, especially when allowance is made for the differences in the equivalent weights of the elements. The total number of mg. equivalents of K, Na, Ca, and Mg per 100 g. dry matter were:

	Series				
Strip	O	N	A	AC	C
5	321	331	325	315	300
6	319	333	342	359	332

Thus, a deficiency of one base was accompanied by an increase in one or more of the others. The inverse correlation between the contents of the different bases is readily seen from Table 13, for example, when the sodium and calcium contents are compared.

Phosphate.—Phosphate-content as per cent. of dry matter was almost the same in the leaves as in the roots, and varied little with fertilizer treatment. Consequently, the differences in the total weight of phosphate contained in the crops merely reflect the differences in yield.

The 36 lb. of P_2O_5 per acre present in the roots of the heaviest yielding plot, 6–AC, represents about half the amount supplied in the dressing of $3\frac{1}{2}$ cwt. per acre of superphosphate, but the percentage recovery in the crop of added phosphate cannot be calculated, for there is no information on the phosphate-content of crops grown without added phosphate.

The analyses of the ash constituents included determinations of the contents of iron, silica, chloride, and sulphate, in addition to those shown in Table 13. The contents of iron and silica were very low, and of similar magnitude (0·2–0·3 per cent. Fe_2O_3 and SiO_2 in the dry matter of the leaf, and 0·03–0·07 per cent. in the root). Addition of potash slightly increased the silica content. The reliability of the sulphate and chloride figures is doubtful, but there is evidence that the chloride-content was greater on

the sulphate of ammonia plots than the others, an effect attributable to the fact that, in the years under consideration, the nitrogenous fertilizer applied to these plots consisted of equal weights of sulphate and chloride of ammonia.

The nature of the fertilizer action of sodium salts.—The analyses of potash- and sodium-content given in Table 13 do not support the idea that sodium salts exert their beneficial effect on the growth of mangolds indirectly by increasing the availability of the potash present in the soil. This view was commonly stated in the older text-books, and is still held by many farmers, who fear that the regular use of sodium salts as fertilizer would exhaust the soil of potash. On the contrary, Table 13 shows that, compared with sulphate of ammonia, nitrate of soda in conditions of low potash supply (strip 5) caused only a small increase in the uptake of potash, although it doubled the yield of the crop; in presence of adequate potash (strip 6) it appreciably reduced the potash-uptake while still increasing the yield by about 2 tons of roots per acre.

Addition of nitrate of soda caused a large increase of soda-content above that of plants receiving sulphate of ammonia, and it is reasonable to conclude that the effect of sodium salts arises from the presence of sodium in the plant in higher concentration. Sodium salts are particularly beneficial when the supply of potash is low. This suggests that sodium may act as a substitute for potassium in the metabolism of the plant, but the possibility that sodium has specific nutrient effects is not ruled out. This interpretation of the fertilizer action of sodium salts is supported by recent investigations of the effect of agricultural salt on sugar-beet.

Change in composition of mangold roots on storage.—N. H. J. Miller [8] studied the change in composition of mangolds during storage for varying periods after lifting. The methods were inadequate on modern standards, but so far as they go, the results show that, between November and March, losses other than of water were small. During the next three months the loss of dry matter increased rapidly, and by July amounted to about 20 per cent. of that originally present. Change in sugar-content accounted for most of the dry-matter loss, and of the sucrose remaining, about half was inverted. In practice, mangolds are consumed before the stage at which appreciable loss occurs.

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THE FEEDING-VALUE OF FLAX BY-PRODUCTS

II. FLAX SHIVE

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FARMERS consider flax shive to be worthless as a fodder or a fodder substitute. Indeed, flax shive is regarded with disfavour as a bedding material because stock may then eat some of it. It is not, therefore, surprising that digestibility data are lacking for this material. During the emergency period the feeding-value of flax shive came under review, and this led to digestibility trials being undertaken in order to secure more definite information on the subject.

A representative sample of shive was secured from a large flax-spinning concern. The shive was then reduced by means of a hammer mill to fragments about $\frac{1}{8}$ in. in length, and was fed in this state. Each trial involved collection of faeces over a 10-day period.

It proved difficult, if not impossible, to induce sheep to consume a ration consisting entirely of ground shive. The material was, therefore, fed in admixture with equal weights of a sample of ground ryegrass-seed cleanings known to be palatable to sheep. The digestibility coefficients of the fraction of ryegrass-seed cleanings concerned were known for each of the two experimental sheep. These individual coefficients were used in calculating the digestible constituents of the shive by difference.

In addition to the direct trials with ground shive, similar trials were conducted with flax shive from the same bulk sample, but which had been treated by soaking in 1·5 per cent. caustic soda solution for 24 hours, washing well, and then drying in the oven. (Attempts to induce sheep to consume a ration of undried shive pulped in this fashion were unsuccessful, even after additions of casein, salt, and fenugreek.)

The analyses of the shive and ryegrass-seed cleanings used are given in Table 1. The conventional analyses were made by the standard methods. In addition 'crude fibre' was estimated as proposed by Norman [1]; lignin was estimated by the method of Norman and Jenkins [2], the crude-lignin figure being corrected by deducting its content of $N \times 6{\cdot}25$; crude cellulose was estimated by the acetic acid–nitric acid technique of Kürschner and Hanak (1930) as modified by Crampton and Maynard [3]. The actual analyses of the materials fed in individual trials, as ascertained on bulked aliquots of the daily feeds, varied slightly from these average figures, but the variations involved were relatively insignificant. A comparison of the composition of the alkali-treated shive with that of the untreated shive reveals little difference in respect of the usual conventional fractions, but differences appear when the carbohydrate fraction is partitioned by means of the modified fibre-method of Norman [1], or by estimations of lignin and crude cellulose.

Table 1 includes calculated average digestibility coefficients for the shive, and starch-equivalent values calculated by Kellner's method and using these coefficients. The results of the digestibility trials are, however, set out in some detail in Table 2, because the conventional calculation of the digestibility coefficients (i.e. on the assumption that the ryegrass-seed cleanings retained the same digestibility coefficients when fed in admixture with shive as when fed alone) leads to negative digestibility coefficients for some constituents of the shive and to negative calculated S.E. values. This may be expressed by saying that the shive had a

TABLE 1. *Composition and Digestibility of Flax Shive*

	Flax shive (untreated)		*Flax shive (alkali-treated)*		*Ryegrass-seed cleanings (special mixture)*	
	Dry matter per cent.	*Digest. coeff.*	*Dry matter per cent.*	*Digest. coeff.*	*Dry matter per cent.*	*Digest. coeff.*
Crude protein . .	2·9	..	2·1	..	14·0	..
True protein . .	2·7	−115	2·1	−112	13·6	57·1
Ether extract . .	1·2	77	0·8	120	7·7	73·5
N-free extract (Weende)	28·2	−5	28·3	−2	47·5	68·0
Crude fibre (Weende) .	64·9	17·9	65·3	14·7	17·4	36·2
Ash	2·8	..	3·5	..	13·4	..
Starch equivalent . .	−9·7	..	−9·3	..	52·9	..
N-free extract (Norman)	30·5	5·4	24·5	12·7	37·6	76·4
Crude fibre (Norman) .	62·6	12·0	69·1	11·6	27·3	36·2
Lignin. . . .	20·9	8·8	24·0	7·9	10·4	1·7
Crude cellulose . .	37·4	11·3	43·8	21·2	15·2	48·8

Note: The data for shive are in each case the averages for two sheep fed similar amounts.

negative feeding-value, or that it reduced the digestibility of the ryegrass-seed cleanings, it being immaterial from the practical standpoint which way this result is expressed.

The results strongly support the opinion of practical men that flax shive is valueless as a feeding-stuff, and that it may even have a negative value by reducing the feeding-value of materials with which it is fed.

During the war the development of the use of green scutched flax provided shive of slightly superior analysis to that used in the present study [4]. Whilst digestibility trials do not appear to have been conducted with such shive as yet, it is improbable that its feeding-value is sufficient to justify its use as a roughage.

Treatment of cereal straws with dilute caustic alkali followed by washing is well known to yield a material ('straw pulp') of enhanced feeding-value [5]. The observations now reported suggest that this simple treatment does not effect a similar improvement in the case of flax shive. It may be remarked that the lignin-content of shive is roughly twice that of cereal straws.

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TABLE 2. *Digestibility of Flax Shive*

		Crude protein		*True protein*		*Ether extract*		*N-free extract*		*Crude fibre (Weende)*		*Fibre (Norman)*		*Lignin*		*Crude cellulose*	
		Sheep 1	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*
Fed in ryegrass-seed cleanings.	gm.	299	298	286	286	167	157	998	1,054	392	367	627	585	210	249	347	345
Indigestible from ryegrass-seed cleanings	gm.	123	136	119	126	35	50	285	353	242	255	374	398	191	263	164	190
In faeces	gm.	229	277	225	267	42	55	995	958	1,384	1,448	1,753	1,773	699	709	1,061	954
Indigestible from shive . .	gm.	106	141	106	141	7	5	710	605	1,142	1,193	1,379	1,374	508	446	897	764
Fed in shive	gm.	68	58	62	55	26	25	667	583	1,390	1,473	1,557	1,570	521	525	935	936
Digestible from shive . .	gm.	−38	−83	−44	−87	19	20	−43	−22	248	280	178	196	13	79	38	172
Digestibility coefficients for shive	%	(−60)	(−146)	(−71)	(−158)	(73)	(80)	−6	−4	17·8	19·0	11·4	12·5	2·5	15·0	4·1	18·4

Digestibility of Alkali-treated Flax Shive

		Crude protein		*True protein*		*Ether extract*		*N-free extract*		*Crude fibre (Weende)*		*Fibre (Norman)*		*Lignin*		*Crude cellulose*	
		Sheep 1	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*	*Sheep 1*	*Sheep 2*
Fed in ryegrass-seed cleanings.	gm.	304	306	295	292	168	169	1,039	998	354	383	568	570	208	229	327	341
Indigestible from ryegrass-seed cleanings	gm.	125	132	123	129	36	54	297	334	223	266	339	388	189	242	155	187
In faeces	gm.	223	228	221	225	35	48	1,042	855	1,391	1,566	1,923	1,859	740	795	1,047	1,050
Indigestible from shive . .	gm.	97	96	98	96	−1	−6	745	521	1,168	1,300	1,583	1,471	551	553	892	863
Fed in shive	gm.	45	49	44	48	15	19	771	486	1,335	1,564	1,735	1,721	608	591	1,093	1,098
Digestible from shive . .	gm.	−53	−47	−54	−48	16	25	26	−35	167	264	151	250	57	38	201	265
Digestibility coefficients for shive	%	(−118)	(−95)	(−123)	(−100)	(107)	(132)	3	−7	12·5	16·9	8·7	14·5	9·4	6·4	18·3	24·1

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Summary

Digestibility trials were conducted on flax shive and on flax shive treated with cold dilute alkali and subsequently washed and dried.

The results support the view that flax shive as ordinarily available is worthless as a fodder and may even reduce the digestibility of other more digestible materials when fed along with them. The alkali-treated shive was not superior to the untreated shive.

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CINCHONA IN UGANDA

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WITH PLATES, 1, 2

Historical.—'What do you think of trying Cinchona?' wrote Emin Pasha to Dr. Schweinfurth in 1883, after giving an amazing account of all the plants he had successfully introduced and grown in the Equatorial Province, which then included the northern part of the present Uganda Protectorate.

But it was not until 1918 that cinchona was introduced to this country; in that year seed of *C. officinalis*, *C. ledgeriana*, and *C. succirubra* was purchased from India. There seem to have been very few trees raised from this seed; a single *Cinchona ledgeriana*, labelled *C. officinalis* in the Botanic Gardens, Entebbe, appears to date from this time. In 1921 seed of *Cinchona robusta*, *C. succirubra*, and a hybrid *C. ledgeriana* × *C. succirubra* was introduced from Amani and sown at several stations of the Agricultural Department; but germination was very poor at all places. In the same year more seed of *C. officinalis*, *C. ledgeriana*, and *C. succirubra* was imported from India; apparently none of this seed grew.

Mr. R. Fyffe, Chief Forestry Officer, in 1921 also imported from Java a packet of *Cinchona ledgeriana* seed which, in contrast to most of the other batches of seed, germinated well. Many seedlings were raised; a ¼-acre plot was planted at Kitubulu near Entebbe and seedlings were distributed to other places. It is from this importation of Java seed that the Uganda cinchona is derived; and it is fortunate that there should have been good germination of a type so well suited to the country, for it is vigorous in growth and has a high content of quinine (Plate 1, Fig. 1). It is fortunate also that the other batches of seed did not grow, and that a relatively pure strain of cinchona is available here, instead of the mixture of interspecific hybrids to be seen in places where different types of cinchona have been planted near to each other, allowed to cross-pollinate, and their seed used for propagation.

The high value of the Kitubulu trees was shown in 1930, when samples from 7 trees on the plot were sent to Messrs. Howards, Ilford, London, for analysis. The report stated that the trees contained an average of 10 per cent. quinine sulphate and that one tree contained 14·75 per cent. By contrast, bark of the Amani *Cinchona robusta*, sent from Bukalasa to the Imperial Institute in 1927, had contained only 3·7 per cent. of quinine sulphate.

Specimens of the Kitubulu trees were sent to the Royal Botanic Gardens, Kew, for critical determination and were named *Cinchona josephiana* Wedd., which appears to be the correct name of most of the cinchona cultivated under the name of *C. ledgeriana*. The Kitubulu strain has leaves broader than those of the usual types of *C. ledgeriana*, and

on that account the suggestion was made that it might be a hybrid (Plate 2, Fig. 3). But the seedlings show no segregation into different types, as would be expected if they were of hybrid ancestry; and the material in the herbarium at Kew shows that many plants wild in South America are of a similar broad-leaved type.

As the trees at Kitubulu were so good, a start was made with trials of grafting in 1931; but the work was discontinued as it was considered that quinine might soon be displaced by synthetic anti-malarial compounds. No interest was taken in the crop until 1935, when Mr. W. B. Hall, of Buchanan's (Uganda) Estates, decided to make trials of it and planted small areas of both the Kitubulu strain of *C. josephiana* and of the Amani strain of *C. ledgeriana*. Planting has been continued on Buchanan's (Uganda) Estates, who have the only considerable area under the crop in Uganda. Smaller plots have been established on several other estates in recent years.

Selection

Quinine still continued to be in demand for the treatment of malaria and, as it seemed that the crop might yet be of value in this country, 50 trees were sampled by taking cores at Kitubulu in 1940. They were analysed by Messrs. Howards in 1941 and showed most interesting results, with contents of quinine (as sulphate) ranging from 0·0 to 10·0 per cent. One important point was evident—that none of the smaller trees had much quinine in their bark, whilst some of the larger trees had a high content of quinine and some had a low one.

Messrs. Howards kindly undertook to carry out more analyses. As they required larger samples than those provided by cores, panels of bark were removed from the trees; these panels measured 40 sq. in., being 2½ in. wide and 16 in. long; their centre was at a height of 1 metre from ground-level. Thirty-seven such samples were taken from the largest trees at Kitubulu and sent to Messrs. Howards in 1942. Their analyses confirmed the value of tree-size as a basis for selection; only 3 trees had bark with less than 5 per cent. quinine sulphate, the lowest content being 3·66 per cent.; and 5 trees had bark containing 10 per cent. or more, the highest figure being 15·07 per cent. quinine sulphate. Twenty-seven samples from rather smaller trees, analysed afterwards at Amani, had lower contents of quinine; the lowest figure was 1·20 per cent. and the highest 10·45 per cent. quinine sulphate.

In February 1944 100 of the largest trees were sampled on two other old cinchona plots of the same strain. These plots were at Kakumiro, in the Mubende district, planted in 1923, and at Kiwago, near Entebbe, planted in 1924–5. The analyses by Messrs. Howards again demonstrated the value of size as a criterion for selecting old cinchona trees; out of 200 samples only 20 had less than 5 per cent. quinine sulphate, while 20 contained 9·8 per cent. or more of quinine sulphate. The Kiwago plot is a large one—it originally covered 7 acres—and many big trees had not been sampled. Bark from 50 more Kiwago trees was analysed at Amani later in 1944, and although the average content of

quinine was not so high as that of the samples sent to Messrs. Howards, yet 2 samples contained more than 10 per cent. of quinine sulphate.

Of the old trees 364 have now been sampled and their bark analysed; the figures show that many of them have a good content of quinine, although they are about 20 years old. It has been proved that the content of quinine in cinchona bark falls off after a tree has passed the age of 6 years, and it is probable that, had the Uganda trees been cut down at the end of 10 or 12 years, the normal cycle for cinchona, their bark would have contained at least 2 per cent. more quinine sulphate. This contention is supported by the facts that the Kitubulu trees, when 8 years old, had an average of 10 per cent. of quinine sulphate in their bark, and that some 6-year-old trees on Buchanan's (Uganda) Estates, raised from unselected Kitubulu seed, had about the same average.

The production of quinine by a cinchona tree does not depend only on the richness of the bark but also on the thickness of the bark and the growth of the tree. To estimate the relative value of trees the figure used has been the product-percentage of quinine sulphate × girth of tree × weight of sample; for, as all samples were of the same area, their weight gave a measure of relative thickness of the bark. Most of the trees sampled were vigorous; many had more than one stem; of those which had a single stem, few had a girth of less than 50 cm. at a height of 1 metre above ground-level; the largest tree with a single stem had a girth of 76 cm.

There is a danger in selecting trees 20 years old, that the trees outstanding at this age would not necessarily be outstanding at 10 or 12 years, the normal age for harvesting. But it is probable that the largest trees have been outstanding throughout most of their life; at any rate, they would not be those which had flowered precociously and whose growth therefore was stunted. Some of the selected trees, in spite of their age, even now flower very little and produce little or no seed.

As seedlings of *Cinchona josephiana* grow so well in Uganda there can be no question of using the more expensive grafted plants for commercial quinine production. The value of a selection will therefore depend on its progeny; and it is not always the best trees which give the best progenies. Seedlings from open pollination will give an indication of the value of selections as mother trees. Therefore seed has been collected from many of the best trees and their progenies are being planted out for observation at Kawanda. Important differences in vigour—a desirable character—and in precocity of flowering—an undesirable character—are already visible, and seedlings from unselected trees have proved to be much more precocious in flowering than those from selected trees.

There will be no need for unselected seed to be sown in future, for the plot at Kakumiro has been thinned and all the poorest trees removed, leaving 81 trees of great vigour and good quinine-content. This plot will furnish a reliable supply of seed until seed-gardens of grafted trees, including the best clones from Kitubulu, Kiwago, and Kakumiro, may become available. Preliminary trials of side-grafting indicate that the clones differ greatly in the ease with which they may be propagated in this way.

It seems unlikely that many better strains of cinchona will be available than the best of those already in the country. *Cinchona succirubra* seedlings are no faster in growth than those of the local *Cinchona josephiana*, and their content of alkaloids, especially of quinine, will be much less. As laid down by the investigation on cinchona prospects in India [1]: 'In this investigation it is the land considered suitable for *Cinchona ledgeriana* that has been selected. *Cinchona ledgeriana*, when properly cultivated, yields the most profitable return because it contains the maximum quantities of quinine. To recommend any other variety in preference would go against the verdict of history.'

Climatic and Soil Requirements

Evans [2] has stated that a mean temperature of about 75° F., a mean minimum of 60° F., and a mean maximum of 85° F. are probably ideal temperatures for the cultivation of *Cinchona ledgeriana*. At Entebbe, altitude 3,878 ft., where cinchona has grown so well, the figures are: mean 69·8° F., mean minimum 63·3° F., mean maximum 78·6° F. Cinchona grows well in the Toro district, though not so rapidly as near Entebbe; at Fort Portal, altitude 5,050 ft., the temperatures are: mean 64° F., mean minimum 54·7° F., mean maximum 78·7° F.

The annual rainfall in both places is less than the figure of 75 to 150 in. given by Evans, but, as he points out, distribution is more important than amount. At Entebbe the average is 59·13 in., and at Fort Portal it is 56·92 in.; but it is very well distributed and is supplemented by heavy dews. At Kakumiro, altitude about 4,500 ft., the temperatures lie between those of Entebbe and Fort Portal and the average annual rainfall is 52·67 in.

A striking proof of the suitability of the climate to cinchona has been the way in which the plots at Kiwago and Kakumiro were abandoned for years and yet the cinchona remained in good condition. The canopy of the trees prevented undue growth of many injurious weeds and grasses; but there appeared other plants typical of forest undergrowth, and forest climbers. And there was abundant regeneration of the cinchona, a mass of seedlings growing in some places: a sure proof that the conditions suited the species.

It has been stated that cinchona in Java grows rapidly at low altitudes but has a low quinine-content. In spite of the rapid growth of *Cinchona josephiana* in Uganda its content of quinine is good. It has also been shown [3] that soil fertility has a great influence on the richness of the bark; but the three plots from which samples have been taken are all on soils poorer than the average; those at Kitubulu and Kiwago are on leached lakeside soils, and the Kakumiro plot is on land where arabica coffee had died out.

Cinchona is stated to prefer soil that is light in texture and preferably of volcanic origin. But it has been found to grow well on the heavy red earths so common in Uganda; if these red earths are too much cultivated when they are wet their physical condition is bad; but if cinchona is planted on them soon after the land has been cleared from elephant grass and the structure is good the crop grows well.

Elephant grass is regarded in the Belgian Congo as an indicator of good soil for cinchona [4]. Stoeffels mentions that sloping land is often better than flat and that a range of pH 4·5 to pH 6·5 is suited to cinchona, with an optimum of pH 5·6. There are large stretches of undulating land in Uganda, with an average rainfall of about 50 in., with a dense cover of elephant grass, and with a reaction of about pH 5·5 to pH 6·5. All this land is suited to cinchona, and a vast area could be put under the crop.

But there is a large population and many other export crops are grown in some of the elephant-grass areas of Uganda, for example, in Kyagwe on the northern shore of Lake Victoria. Other areas, farther from the railway, have less population and need crops which can be grown productively so that the inhabitants may secure employment near their homes and need not migrate in search of wages. Two such areas are to be found in the north of the Mubende district and to the south of Fort Portal, where there are stretches of elephant-grass land quite unoccupied. Both of these areas show good prospects for cinchona development as they have suitable soils, suitable climates, and many labourers living nearby.

Quinine could be produced very cheaply in these areas. It is much cheaper to clear and prepare land from elephant grass than from forest; the structure of the soil is excellent and, together with the large amount of organic matter from the roots and stems of the grass, it prevents erosion. And elephant-grass land is practically free from the fungus *Armillaria mellea*, which is abundant in most forest soils and to whose attacks cinchona is very susceptible.

Another reason why lightly populated areas are best for cinchona is the fact that there are few house sites where the soil has been made alkaline. Cinchona will not grow well on alkaline soil—the leaves turn yellow and mottled with red, the growth is stunted, and the plants may even die completely (Plate 2, Fig. 4). The application of lime has stimulated growth of cinchona planted on acid soils in Java [3] and the Belgian Congo [4]; but there is probably less need for lime on the nearly neutral soils of Uganda.

The Kigezi district in the south-west of Uganda is another area which would benefit from more export crops. Plots of *Cinchona josephiana* were planted in several places in 1927, and some old trees still remain. But the growth in Kigezi, at altitudes above 5,000 ft., has been much slower than in other places at altitudes below 5,000 ft. This is also shown by the young plants on Kachwekano Farm, near Kabale, at an altitude of 6,000 ft., which are smaller than plants of the same age at Kyembogo, near Fort Portal, altitude 5,000 ft.; and growth at Kyembogo is slower than growth at altitudes of 4,000 ft. near Lake Victoria.

A small plot of a good strain of *Cinchona officinalis*, imported from South India in 1941, is making excellent growth on acid soil at an altitude of about 6,500 ft. on Kachwekano Farm; this type would be useful on the higher, cooler parts, but at 5,000 ft. on the less acid soil of Kyembogo Farm its growth is much poorer than that of *Cinchona josephiana*. For cheap quinine production it would be better to grow

Cinchona josephiana at low altitudes than *Cinchona officinalis* at high altitudes; but the varying reactions of different *Cinchona* spp. to soils and climates are of great interest.

Cultivation

As so many batches of imported cinchona seed grew badly, or not at all, it seemed that the seed might lose its germinating capacity quickly. But trials of local seed have shown this is not always the case. Fresh seed has given about 90 to 98 per cent. germination; seed 9 months old, about 70 to 80 per cent.; seed 20 months old, about 50 per cent.; and seed 32 months old, about 5 per cent. No special care has been taken of this seed, which was stored in gunny bags in the laboratories at the Kawanda Experiment Station.

If cinchona seed is to germinate well it must be exposed to the light; laboratory tests at Kawanda have given these results:

Time	*Percentage of germination*	
	Seed in light	*Seed in darkness*
1st week	0	0
2nd ,,	29	0
3rd ,,	44	7
4th ,,	4	11
5th ,,	0	8
6th ,,	0	5

Therefore it is essential that nursery beds must be arranged so that seeds are exposed to light but are protected from rain; if the soil is too wet the seedlings will damp off. A simple type of seed nursery, constructed of local materials, costs only Shs. 400/- to build and has served for two seasons with minor repairs to the thatch and replacement of the soil in the beds. There are 8 beds, each 30 ft. long and 4 ft. wide, including their brick borders; and they are filled with good grassland top soil, passed through a wire screen of $\frac{1}{4}$-in. mesh, not pressed down, but smoothed over with a shaped board, so that the centre of the bed is 3 in. higher than the sides. Each bed is covered with a steep thatched roof, arranged so that the rain drips down into the centre of the path between one bed and the next. Good drainage is essential, and the beds must be made on the lower slopes of a hill, not in the bottom of a valley.

The soil of the beds is watered, and left for 2 weeks; as weed seedlings appear they are removed. The surface of the bed is then moistened, the seed is scattered over it evenly at the rate of $\frac{1}{2}$ oz. per bed (i.e. rather less than 1·5 gm. per sq. m.). The seed is then sprayed so that it may adhere to the soil; and it is sprayed at intervals until it germinates; with so fine a seed a watering-can should not be used. Correct spraying is the secret of success; it is done at a height of 2 or 3 ft., so that the moisture settles on the soil as a fine mist. The seeds and the soil should be kept slightly moist, but must not be sodden; in dry weather spraying

may be needed three or four times a day; in wet weather it may not be needed at all.

Constant supervision was needed at first to ensure correct spraying; but much less has been needed when Africans became trained in the work. The seedling disease caused by Rhizoctonia, which causes such difficulties in cinchona nurseries in many countries, has not been a great trouble at Kawanda. It may be that the disease is controlled by the relatively dry climate, or that the grassland soil used here has a fungus flora more antagonistic to Rhizoctonia than the forest soil used in other places. Crickets have been a nuisance, for they attack both the seeds and the seedlings; but they have been controlled by poisoning with a bait of bran moistened with molasses and a little sodium arsenite.

Cinchona seed usually begins to germinate in the laboratory 8 days after it has been sown; germination starts after 16 days in the nursery at Kawanda. Care must be taken that the seedlings do not dry out before their roots have entered the soil, or that they are made too wet. Under the warm conditions at Kawanda the most precocious seedlings reach a height of 1 in., with 6 or 8 leaves, by the age of 3 months; they are then ready to be pricked out, which should be done without delay, so that other seedlings may have room to develop. Care must be taken that seedlings do not become drawn up in the seed-beds, for those with weak, soft stems form plants with a kink above ground-level and often grow badly, or die, in the field. Successive batches of seedlings may be removed from the seed-beds over a period of 2 or 3 months and pricked out in nursery beds.

Beds for pricking out should be of good soil, deeply dug, and shaded at the top and sides. They should not be more than 4 ft. wide and should have narrow paths between, so that pricking out, watering, and weeding may be done without treading on the beds. The spacing at which seedlings are pricked out should be at least 6 in. square. Careful training is needed in this work; the seedlings must be lifted gently, their stems must not be pinched in handling, and, most important of all, they must be planted at the same level as in the seed-bed, no deeper. Seedlings may be sprayed until they become established; then a watering-can may be used to keep them moist.

Watering must be done carefully, for even large seedlings are attacked by Rhizoctonia, and although they may not be killed outright, yet their leaves turn reddish, their growth is stunted, and their roots die back. Affected seedlings often recover if the soil is allowed to become drier, and if a dressing of bone-meal is given (1 oz. per sq. yd.) they will overtake the healthy seedlings. Bone-meal has a most stimulating action on cinchona; seedlings heavily manured with bone-meal had double the dry weight of seedlings on ordinary soil after a year of growth.

But there is no need to manure cinchona seedlings under normal circumstances in Uganda, as they grow very fast. Stoeffels [4] has given the following periods for raising cinchona seedlings in the Belgian Congo, near Lake Kivu at an altitude of about 5,400 ft.: germination, 1 month; pricking out, 7 months; planting in the field, 15 to 20 months. At Kawanda, altitude 3,900 ft., the periods are: germination, 16 days;

pricking out, 3–4 months; planting in the field, 12–14 months. Seedlings actually have been successfully planted out within 9 months of sowing the seed, when they were about 8 in. high.

The best height of seedlings for planting out is about 1 ft.; sturdy plants are needed, from which the shade has been removed for 2 months, at least. Larger plants, 20 months old and up to 5 ft. high, have been successfully planted as striplings with their leaves removed. As with pricking out in nursery beds, so also with planting in the field, it is essential that cinchona should not be planted deeply or the seedlings will rot off. When land is cleared from elephant grass a thorough deep digging is needed to get out the root-stocks, and there is no need to make holes for planting: the labourers scoop out the loose soil with their hands and the danger of deep planting is avoided.

As there is such vigorous growth of cinchona in Uganda when the local seed is used, it seems probable that a wider spacing may be needed than that of 0·80 m. or 0·90 m. advised for the Belgian Congo [4]. Seedlings were planted out at different spacings on the Kyembogo Farm near Fort Portal, and after 24 months of growth those at a spacing of 4 ft. square were the largest and were nearly 8 ft. high; those at 3 ft. square were rather smaller (Plate 1, Fig. 2); those at spacings of 2 ft. and 1 ft. suffered from root competition in dry spells. It seems probable that a spacing of 4 ft. triangular would be very suitable in Uganda; triangular spacing has a great advantage over square spacing in that it gives a better cover over the ground, both from the young plants and after thinning has been started.

The best cycle of cultivation and harvesting cinchona in Uganda is not yet known, but it is probable that it will be the same as in most other countries—of pruning off the lower branches from the age of 3 years onwards, of taking out the poorer trees from the age of 4 years onwards, and of complete uprooting at the age of about 12 years. Land could then be put under a cover of elephant grass for 3 years before it is cleared again and replanted with cinchona.

Pests and Diseases

As mentioned above, seedlings may be attacked by Rhizoctonia, but the disease does not seem to be as rampant in Uganda as in some other countries. Crickets are a nuisance in nursery beds. The Mosquito Bug, Helopeltis, attacks seedlings during dry spells, sometimes quite heavily, but may be easily controlled by dusting with pyrethrum powder; if no control is given the pest disappears at the onset of the rains and the seedlings soon recover. Large grasshoppers sometimes do much damage by biting off the tops of the seedlings after they are planted in the field, and should be searched for early in the mornings.

Helopeltis also is found occasionally on plants in the field during dry spells; but on no occasion has it been seen to check the growth appreciably. Cinchona is very liable to death from root disease caused by the fungus *Armillaria mellea*; many trees at Kiwago have died from it. It is on that account that land under elephant grass, where the fungus is rare, is recommended for cinchona in preference to forest soils, where

the fungus is often abundant. A watch should be kept for the disease, even when the crop is planted on elephant-grass land.

Costs, Yields, and Returns

The ease with which cinchona may be grown in Uganda renders its cultivation cheap. Mr. M. G. de Courcy Ireland, who planted up 15½ acres on Kyembogo Farm in 1943, found that costs there were low. Without counting overhead charges or European supervision, it cost less than 4 cents (of a shilling) to raise a seedling to the size for planting out. And, again without overhead charges or European supervision, it cost less than Shs. 400/- to clear, plant, and weed an acre; this figure included much planting at close spacings, and at a commercial spacing of 4 ft. costs would have been much less. As the plants grow so quickly they soon cover the soil, and little weeding is needed after the first year even at the wide spacing of 4 ft.

The very vigorous growth of the broad-leaved *Cinchona josephiana* in Uganda in comparison with that of narrow-leaved types of *Cinchona ledgeriana* seen in Bengal, in the Belgian Congo, and in Tanganyika suggests that very heavy yields may be expected here. No exact figures are obtainable, for all the trees recently planted on the stations of the Agriculture Department are still young. A typical 2½-year-old tree at Kawanda was found to have about 0·40 kg. of bark; therefore a yield of 600 kg. per acre might be expected even at this early age, if the spacing were 4 ft. square.

Some indication of yields from mature cinchona in Uganda was obtained when the plot at Kakumiro was thinned. This plot had been planted in 1923 with 576 trees at a spacing of 6 ft. square, and therefore measured rather less than half an acre. In 1944 only 259 trees remained; and 178 of the poorest—some of which were very poor—were cut down, and the bark removed from the roots, trunks, and thicker branches. The yields were:

Branches	902 lb.	sun-dried bark;	5·4%	total alkaloids.
Trunks	2,510	,, ,,	7·7%	,,
Roots	501	,, ,,	4·2%	,,
Total	3,913			

The best 81 trees are retained for seed-production and may be assessed to have an average of at least 50 lb. of bark per tree, for some of the poorer trees cut out had a greater yield than this. Therefore it appears that at least 4,000 lb. of bark remains on the plot and that the total production on half an acre was about 8,000 lb. This would correspond to about 18,000 kg. per hectare, after 21 years (mostly of neglect), which compares quite favourably with the yield of 10,000 kg. per hectare in a 12-year cycle, considered good in Java, with correct attention to the crop. The Kakumiro bark was sold to the Totaquina Factory, Dar-es-Salaam, for Shs. 4,430. As at least an equal amount of bark, which is known to be much richer, remains in the plot, the total value of bark there at present prices must have been about £500, a good figure for a neglected plot, under half an acre, planted on poor soil.

Now that Java is freed, with its large reserves of cinchona bark, and there is the increasing use of synthetic drugs to combat malaria, and the synthesis of quinine itself, the future of cinchona planting is very uncertain. Individual planters feel reluctant to invest capital in a long-term crop whose value when mature cannot be predicted. But the existing plots show that with the relatively low costs of planting in Uganda, the excellent growing conditions, and the good strain of seed available cinchona production should be as economical here as anywhere; and that with due regard to seed selection and manuring—for cinchona is a crop which corresponds greatly to soil fertility [3]—yields in Uganda should be as great or greater than in any other country.

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FIG. 1. The plot of *Cinchona josephiana* at Kitubulu, near Entebbe. The trees are 22 years old

FIG. 2. *Cinchona josephiana*, 24 months old, on the Kyembogo Farm, near Fort Portal. The trees are at a spacing of 3 feet square and are 6 to 7 feet high

FIG. 3. Leaves flowers, and fruits of *Cinchona josephiana*

FIG. 4. The effect of alkaline soil on *Cinchona josephiana*. On the left are leaves of a normal plant and on the right are leaves of a plant growing on a house site

RAINFALL OF INDIA: A BRIEF REVIEW

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1. *Introduction*

A DETAILED discussion of Indian rainfall would fill volumes. In a short article like the present all one can attempt is to take a bird's-eye view of the subject.

A history of Indian rainfall is really a history of the well-known south-west monsoon. We have reliable records for about 60 years. As judged by these records, what is the dependability of rainfall in different parts of this vast sub-continent, and what are the chances of success of agriculture in different parts of the country? How often in a century is the monsoon rainfall so conspicuously in excess (flood) or in defect (drought) as to cause widespread havoc and failure of crops? Which are the regions in India with minimum of weather-risk? Do such risks occur at random or is there any regularity or law governing the time and place of their occurrence? What are the large-scale and long-term measures which the State can undertake in order to reduce weather-risks? In what parts of India will such developments be practicable? These are some of the questions which deserve consideration. In what follows, resort will be had to self-explanatory diagrams and tables so as to secure brevity.

2. *Physical and Climatic Features*

Figs. 1 and 2 show the distribution of the mountain and river-systems and of the normal annual rainfall of India. The areas of very heavy rainfall are to the windward side of the Western Ghats, the hills of Assam, and the great Himalayan barrier. These are the watersheds from which originate the major river-systems of the country. Elsewhere, in the plateau of the Deccan, the Gangetic plains of north India, and the plains of the Carnatic, the effects of orography are less pronounced or are completely absent and the rainfall is only moderate. In the north-west, the Punjab, NW. Frontier Province, Sind, Baluchistan, and the desert of Rajputana constitute the driest area of the country.

Table 1 gives the normal rainfall in different seasons of the year and during the year as a whole in the 30 subdivisions into which India may be divided (see Fig. 3). The four seasons are: winter, December to February; summer or pre-monsoon, March to May; monsoon, June to September; post-monsoon, October to November. In columns (2) to (5) the figures within brackets are the seasonal amounts expressed as percentages of the annual rainfall.

A study of these figures reveals at once that India is truly the land of the monsoons. With the exception of Kashmir, the NW. Frontier Province, and Baluchistan in the north and SE. Madras in the south, *a very large percentage of the annual rainfall over the country occurs during the south-west monsoon* (June to September). In the extreme north a

good proportion of the annual rainfall is contributed by winter precipitation, whilst in SE. Madras nearly half the annual rainfall occurs during the post- or retreating monsoon period (i.e. after September).

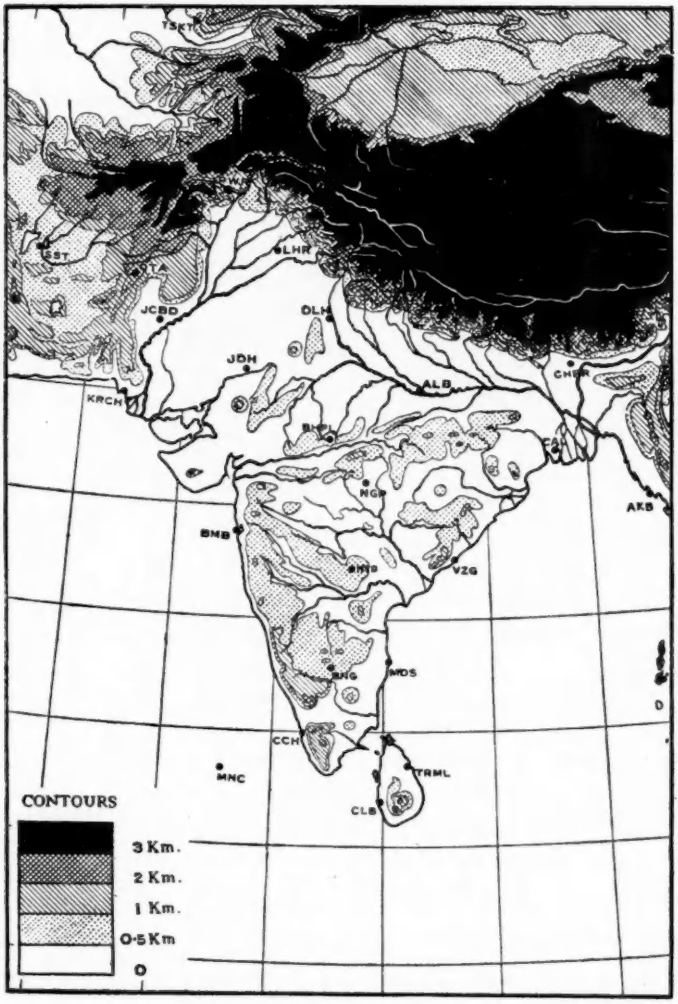

FIG. 1. Relief map of India.

Besides the setting in of the monsoon early in June, its extension into India during June and July, and finally its retreat southwards in September and October, we have also to consider the other major phenomena like cyclonic storms and depressions.

TABLE 1. *Normal Seasonal Rainfall in the 30 Rainfall Subdivisions of India*

Subdivision (1)	*Winter Dec. to Feb.* (2)	*Summer or Pre-monsoon Mar. to May* (3)	*Monsoon June to Sept.* (4)	*Post-monsoon Oct. to Nov.* (5)	*Year* (6)
1. Assam	2·38 (2·4%)	25·06 (25·7%)	64·26 (65·8%)	5·96 (6·1%)	97·66
2. Bengal	1·53 (2·0)	12·42 (16·5)	56·01 (74·5)	5.17 (6·9)	75·13
3. Orissa	1 ·82 (3·2)	5·62 (9·9)	44·49 (78·2)	4·98 (8·8)	56·91
4. Chota Nagpur	2·57 (5·0)	3·64 (7·1)	42·71 (83·4)	2·26 (4·4)	51·18
5. Bihar	1·41 (2·9)	3·30 (6·8)	40·96 (85·0)	2·54 (5·3)	48·21
6. U.P. East	1·53 (3·9)	1·12 (2·9)	34·44 (88·0)	2·04 (5·2)	39·13
7. U.P. West	2·27 (6·0)	1·36 (3·6)	32·98 (87·8)	0·97 (2·6)	37·58
8. Punjab, E. & N.	2·76 (11·9)	1·89 (8·1)	18·23 (78·4)	0·37 (1·6)	23·25
9. Punjab, SW.	1·28 (13·7)	1·36 (14·5)	6·58 (70·4)	0·13 (1·4)	9·35
10. Kashmir	9·12 (22·1)	9·09 (22·0)	22·19 (53·7)	0·94 (2·3)	41·34
11. N.W.F.P.	3·36 (20·0)	4·18 (24·9)	8·65 (51·5)	0·62 (3·7)	16·81
12. Baluchistan	3·50 (45·6)	2·03 (26·4)	1·89 (24·6)	0·26 (3·4)	7·68
13. Sind	0·67 (10·4)	0·41 (6·4)	5·28 (82·4)	0·08 (1·2)	6·44
14. Rajputana, W.	0·62 (4·8)	0·56 (4·3)	11·74 (90·0)	0·12 (0·9)	13·04
15. Rajputana, E.	0·96 (3·8)	0·78 (3·1)	22·91 (90·9)	0·55 (2·2)	25·20
16. Gujerat	0·22 (0·7)	0·24 (0·7)	31·46 (96·2)	0·77 (2·4)	32·69
17. C. India, West	0·85 (2·5)	0·47 (1·4)	31·56 (93·8)	0·75 (2·2)	33·63
18. C. India, East	1·44 (3·7)	0·79 (2·0)	35·05 (90·9)	1·30 (3·4)	38·58
19. Berar	1·01 (3·1)	0·96 (3·0)	28·10 (87·4)	2·07 (6·4)	32·14
20. C.P. West	1·47 (3·2)	1·14 (2·5)	41·04 (90·4)	1·76 (3·9)	45·41
21. C.P. East	1·58 (3·0)	2·10 (4·0)	46·37 (89·1)	1·99 (3·8)	52·04
22. Konkan	0·28 (0·3)	1·85 (1·7)	102·45 (93·7)	4·75 (4·3)	109·33
23. Bombay Deccan	0·51 (1·7)	2·13 (6·9)	24·41 (79·1)	3·82 (12·4)	30·87
24. Hyderabad, N.	0·67 (1·9)	1·53 (4·4)	29·51 (84·5)	3·20 (9·2)	34·91
25. Hyderabad, S.	0·57 (1·9)	2·10 (7·0)	23·38 (78·1)	3·88 (13·0)	29·93
26. Mysore	0·73 (2·0)	5·47 (15·2)	22·27 (61·8)	7·54 (20·9)	36·01
27. Malabar	2·73 (2·6)	12·61 (12·2)	71·47 (68·9)	16·93 (16·3)	103·74
28. Madras, SE.	4·76 (13·6)	4·53 (12·9)	12·01 (34·2)	13·80 (39·3)	35·10
29. Madras, Deccan	0·74 (3·0)	2·42 (9·9)	15·27 (62·3)	0·09 (24·8)	24·52
30. Madras, Coast N.	1·69 (4·2)	3·44 (8·6)	25·03 (62·3)	10·00 (24·9)	40·16

(1) *Eastern depressions.*—The fluctuations in the intensity of the monsoon itself are to a large extent associated with a series of depressions which mostly originate (or, when they are coming from farther east, strengthen) at the head of the Bay of Bengal and travel in a north-westerly direction across the country towards NW. India, causing heavy rainfall along their track. The frequency of such depressions is 3 or 4 per month during the monsoon months (June to September).

(2) *Western depressions.*—During the period November to May a series of western depressions enter India through Baluchistan and the NW. frontier and move eastwards across North India towards NE. India (Assam–Bengal). These depressions cause cloudy weather and light rains in the plains with snowfall in the Himalayas and are followed by cold waves. Their frequency is, on the average, 2 in November, 4 to 5 per month during December to April, and about 2 in May.

(3) *Cyclonic storms.*—The more severe cyclonic storms usually form in the Bay of Bengal and in the Arabian Sea in the transition periods April to June and October to December. They enter inland and cause considerable precipitation and damage due to high winds and, occasionally, tidal waves, in the coastal tracts. The mode of occurrence of

these storms and their favourite tracks have been discussed in the publications of the India Meteorological Department. On an average

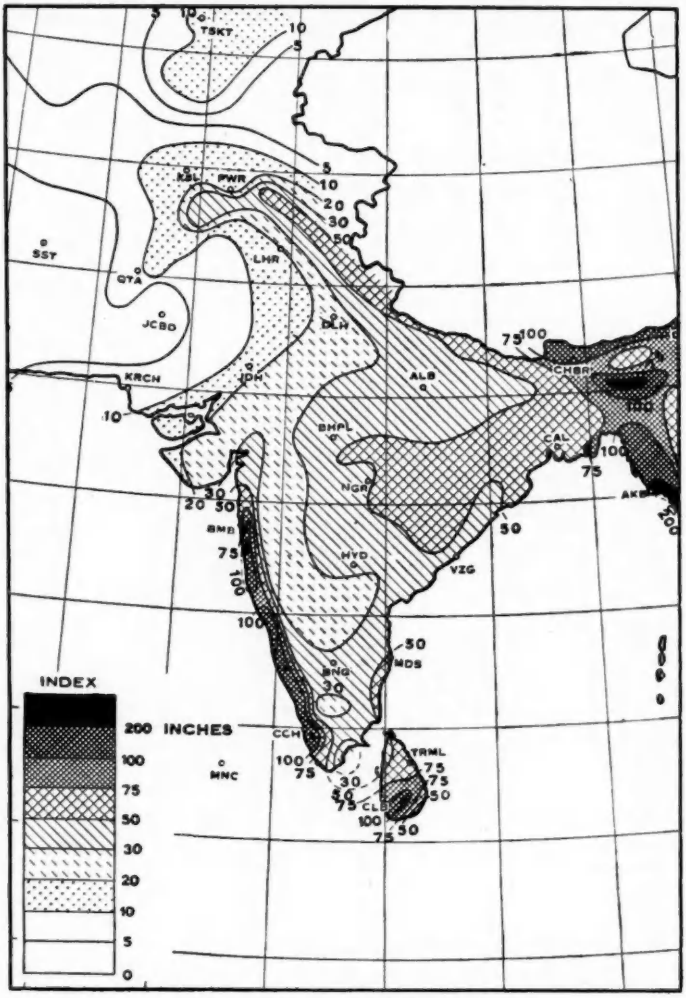

FIG. 2. Annual rainfall in India.

1 or 2 severe cyclones may be expected in the pre-monsoon period and 2 or 3 in the post-monsoon period.

3. *The SW. Monsoon*

(*a*) *Date of establishment.*—As is well known, the success of Indian agriculture depends mainly on the monsoon rains; the farmer looks

TABLE 2. *Date of Establishment of the SW. Monsoon along the West Coast of India*

Year	*Travancore–Cochin*	*S. Kanara*	*Ratnagiri*	*Kolaba*
1891	May 27	June 3	June 19	June 21
1892	,, 22	May 24	May 29	May 31
1893	,, 22	June 4	June 10	June 10
1894	June 1	,, 2	,, 7	,, 7
1895	,, 8	,, 12	,, 14	,, 15
1896	May 30	May 31	,, 1	,, 1
1897	,, 30	June 5	,, 7	,, 7
1898	June 2	,, 3	,, 8	,, 8
1899	May 23	,, 7	,, 9	,, 10
1900	June 6	,, 8	,, 9	,, 9
1901	,, 1	,, 4	,, 7	,, 7
1902	May 31	,, 6	,, 7	,, 12
1903	June 8	,, 11	,, 12	,, 12
1904	May 29	,, 1	,, 7	,, 8
1905	June 6	,, 8	,, 9	,, 10
1906	,, 3	,, 6	,, 7	,, 8
1907	May 31	,, 5	,, 11	,, 11
1908	June 8	,, 10	,, 11	,, 11
1909	,, 1	,, 2	,, 3	,, 3
1910	May 28	,, 2	,, 3	,, 3
1911	June 1	,, 2	,, 4	,, 4
1912	,, 4	,, 6	,, 12	,, 12
1913	May 24	,, 1	,, 6	,, 7
1914	,, 28	,, 5	,, 13	,, 13
1915	June 3	,, 12	,, 17	,, 18
1916	May 26	May 27	May 31	,, 1
1917	,, 26	,, 29	June 4	,, 5
1918	,, 7	,, 15	May 22	May 25
1919	,, 16	,, 26	June 4	June 6
1920	,, 27	June 2	,, 6	,, 6
1921	June 1	,, 3	,, 10	,, 12
1922	May 25	May 31	,, 10	,, 12
1923	June 4	June 11	,, 12	,, 13
1924	May 31	,, 3	,, 10	,, 12
1925	,, 27	May 28	May 29	May 29
1926	,, 28	June 5	June 9	June 10
1927	,, 23	May 27	,, 10	,, 10
1928	,, 31	,, 31	,, 5	,, 7
1929	,, 29	,, 30	,, 1	,, 6
1930	,, 21	June 7	,, 8	,, 9
1931	,, 23	May 29	,, 14	,, 14
1932	,, 14	June 2	,, 3	,, 3
1933	,, 22	May 28	,, 1	,, 1
1934	June 6	June 6	,, 10	,, 10
1935	,, 10	,, 10	,, 12	,, 14
1936	May 20	May 22	May 29	,, 1
1937	June 3	June 10	June 11	,, 12
1938	,, 1	,, 2	,, 2	,, 4
1939	,, 6	,, 6	,, 7	,, 9
1940	,, 7	,, 13	,, 16	,, 18
1941	May 23	,, 3	,, 14	,, 16
1942	June 4	,, 8	,, 12	,, 13
1943	May 12	May 14	May 21	May 21

forward to the onset of the monsoon with great anxiety and prays for a timely and suitable distribution of rainfall during the season. The SW. monsoon has been described in various publications of the India Meteorological Department. Figs. 4 and 5 show the *normal* dates of *onset* and of *withdrawal* of this monsoon in different parts of India. The actual dates of onset as well as the intensity and distribution in time and

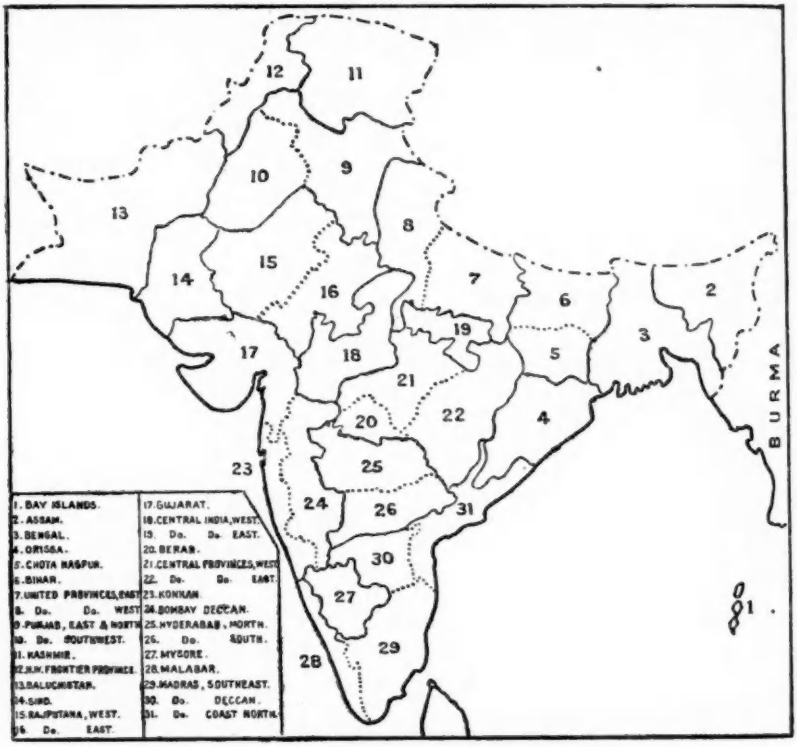

FIG. 3. Map of India showing the rainfall subdivisions.

space of the monsoon precipitation vary from year to year. Table 2 gives the actual dates of establishment of the SW. monsoon in four areas along the west coast of the peninsula. It will be noticed that there is a considerable variation not only in the *dates* of establishment but also in the speed with which the monsoon current moves from the Travancore–Cochin area in the south towards Kolaba in the north (near Bombay). Table 3 below summarizes the information given in Table 2.

As the major agricultural operations have to synchronize with the monsoon rains, the importance of predicting the date of establishment of the monsoon in different parts of the country, the spells of rain and breaks which occur during the season, cannot be over-emphasized.

(*b*) *Survey of the past 70 monsoons* (*1875–1944*): *Frequency of drought and flood years.*—For this purpose the total rainfall during the period June to September is considered. If the deviation of the actual rainfall in a year is more than about twice the mean deviation, that year is defined as a year of flood or drought according as the departure is positive or negative.

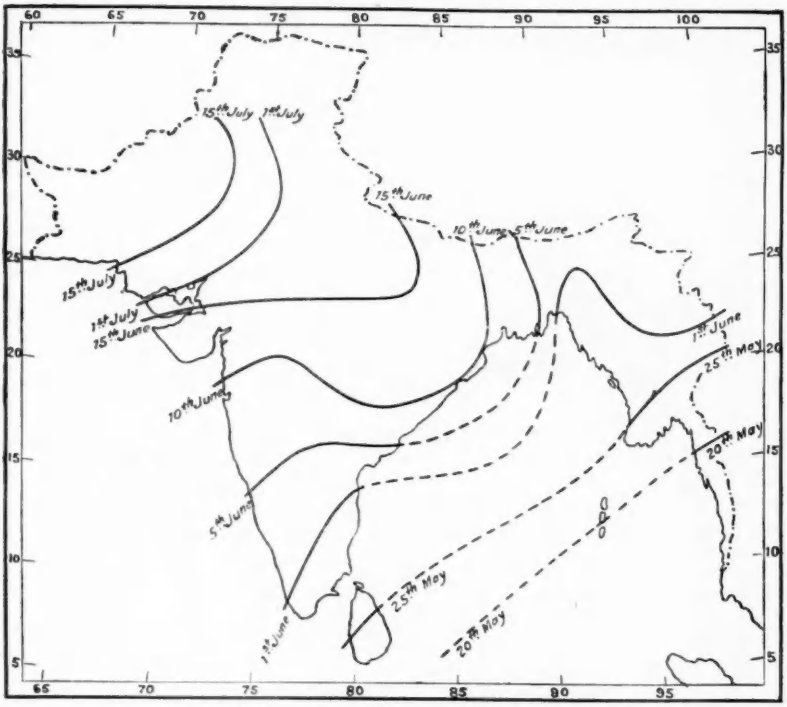

FIG. 4. Normal dates of onset of SW. Monsoon.

TABLE 3. *Dates of Establishment of the SW. Monsoon along the West Coast of India*

Area	*Mean date*	*Standard deviation (in days)*	*Earliest date*	*Latest date*
Travancore–Cochin	May 29	7·0	May 7	June 10
South-Kanara .	June 3	5·7	,, 15	,, 12
Ratnagiri . .	,, 7	5·4	,, 22	,, 19
Kolaba . .	,, 8	5·2	,, 25	,, 21

Fig. 6 shows at a glance how the monsoon has behaved in the past 70 years in each of the 30 rainfall subdivisions of India. In the figure the filled circle indicates a flood, the open circle a drought, and the

spaces which are blank are years and subdivisions with more or less normal monsoon rainfall. At the bottom of this diagram are given, for each subdivision, (1) the normal monsoon rainfall, (2) the mean deviation, (3) the limit for abnormality, i.e. the amount by which the actual rainfall should be in excess or defect if it is to be labelled as 'abnormal' (flood or drought, as the case may be), (4) the total number of floods during the period 1875 to 1944, (5) the total number of droughts during

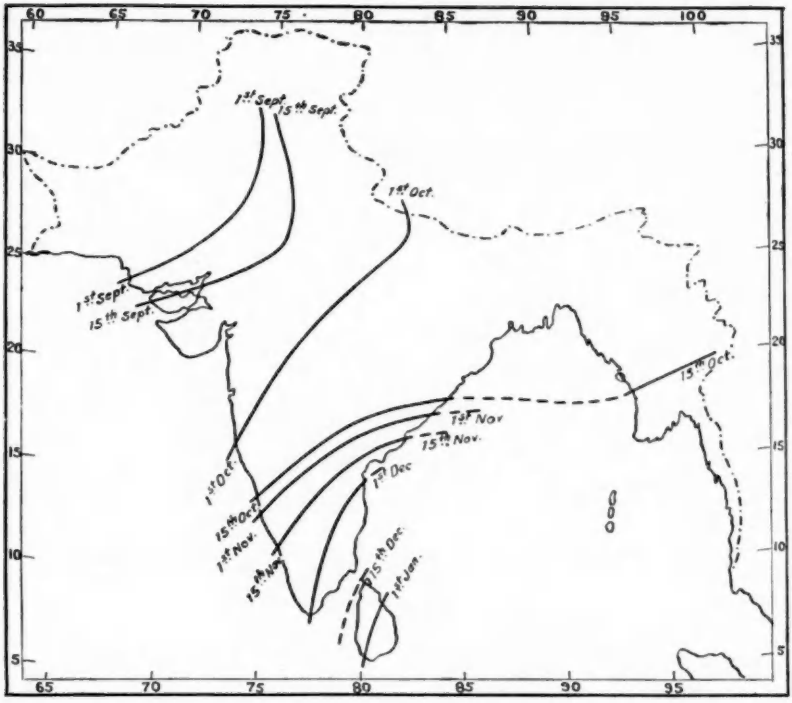

FIG. 5. Normal dates of withdrawal of SW. Monsoon.

the period 1875 to 1944, and (6) the total number of abnormal years (i.e. floods plus droughts) during the period 1875 to 1944.

These figures show that when we consider a sufficiently large number of years, the frequencies of floods and droughts tend to equalize; also, areas with a very low rainfall, e.g. Baluchistan, Sind, Rajputana, &c., are those where the total number of abnormalities is maximum; in areas like the Konkan, Malabar, Bengal, &c., where the monsoon rainfall is above 40 in., the frequency of abnormal years comes down very much.

It is still more interesting to study the distribution of floods and droughts in the various subdivisions in each year. The years 1877, 1899, and 1918 stand out very prominently as years of general drought. It will be recalled that these were actually years of great famine and

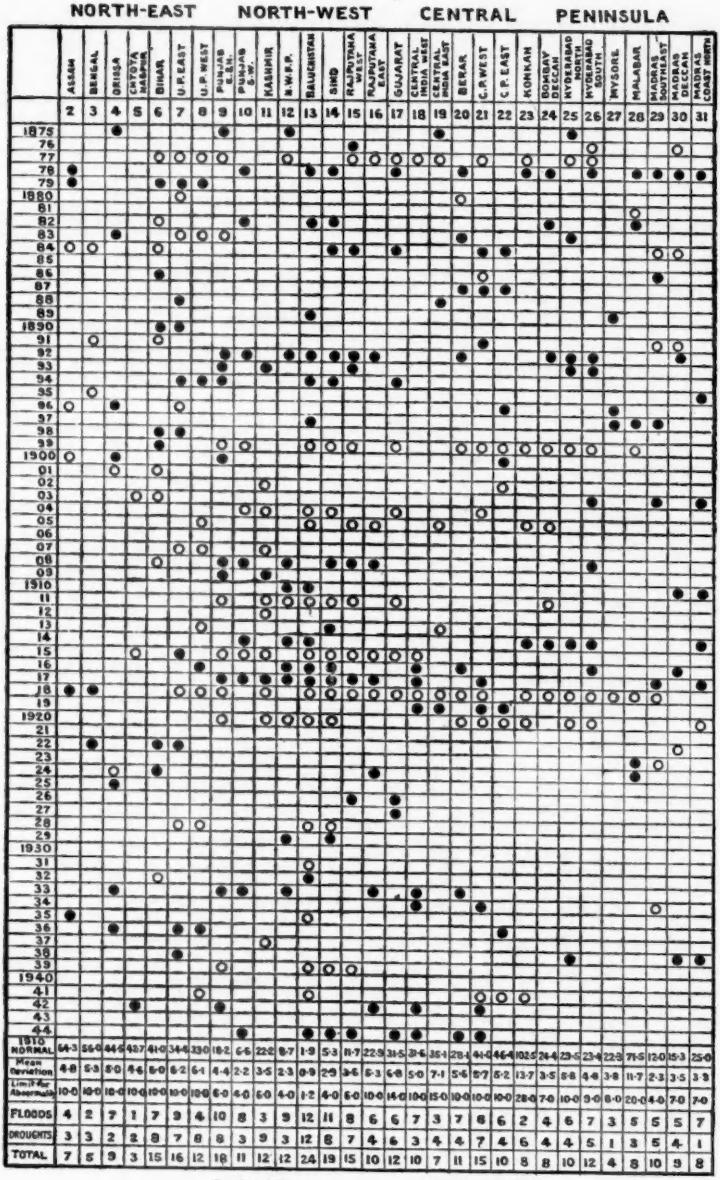

FIG. 6. Floods and droughts in India. Years of floods and droughts have for this purpose been defined as years with abnormality greater than twice the mean deviation.

distress. The year 1920 was one of partial drought, only the north-west and the central parts of the country being affected. The years of general flood are 1878, 1892, and 1917. In two instances at least (1877, 1878, and 1917, 1918) droughts and floods occurred in adjacent years, but there is usually no regularity in time in the distribution of droughts and floods. The chances of one drought year being succeeded by another or a flood year being succeeded by another in a particular subdivision

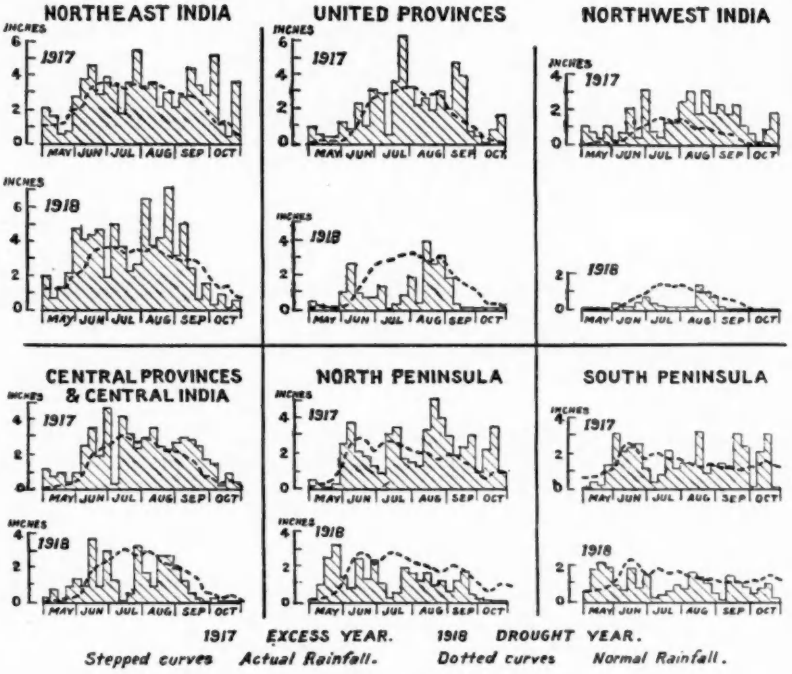

FIG. 7. Progress of the monsoon week by week.

appear to be small. Areas of drought and floods are, however, associated into centres of defective or excessive rainfall in the years in which they do occur. For the rest, the reader can judge for himself from Fig. 6 how liable India is to the incidence of abnormal monsoons.

Before leaving this topic it will be interesting to compare the actual distributions of *weekly* rainfall during the monsoon season of the years 1917 and 1918, as they are likely to show up the contrast, not only in the total rainfall, but also in the distribution thereof. Fig. 7 shows the rainfall distribution in 1917 and 1918, for each of the main divisions: (1) NE. India; (2) the United Provinces; (3) NW. India; (4) Central Provinces and Central India; (5) North Peninsula; (6) South Peninsula.

The dotted curves represent the normal weekly rainfall and the hatched area shows the actual rainfall. There is little contrast between

1917 and 1918 in NE. India as the rainfall was more or less normal in both the years. Over the other five divisions of the country, however, the contrast between the excess and the defect in 1917 and 1918 respectively was very marked.

4. *Contemporary Relationships of Monsoon Rainfall in Fifteen Divisions*

We have just seen that the monsoon rainfall varies from year to year both as regards the total rainfall as well as its distribution during the season. Administrators and others interested in the country as a whole may naturally inquire whether the effects of a deficiency in the monsoon rainfall in one part of the country is likely to be compensated by the effects of excess in some other part or parts.

Table 4 below expresses the relation between the monsoon rainfall in each of the 15 divisions and the remaining divisions in the form of contemporary correlation coefficients. A positive coefficient in the table indicates the two areas concerned are likely to be affected similarly (i.e. both may have heavy rains in some years and deficient rains in other years). A negative coefficient would indicate that a decrease in one is likely to be associated with an increase in the other area. Looking at the correlation coefficients in each row, one notices that a vigorous monsoon over Burma tends to be associated with a subnormal monsoon over India (and vice versa). To a smaller extent, excessive rainfall over NE. India tends to be associated with a defect elsewhere (and vice versa). Elsewhere, in India, i.e., NW. India, Central India, and the Peninsula, the correlation coefficients are generally positive, indicating that departures from normal are likely to be similar over the greater part of India, as indeed the dot-diagram (Fig. 6) does suggest in regard to even pronounced abnormalities like floods and droughts.

5. *Is India's Climate Changing? Are there Secular Variations or Periodicities in Indian Rainfall?*

The longest meteorological records in India are of rainfall at the cities of Madras (from 1813), Bombay (from 1847), and Calcutta (from 1829).

The rainfall data of the above stations as well as of shorter series in the case of some 10 stations in Bihar were examined for periodicity. In some cases there were significant periods, but considering that neighbouring stations do not indicate similar periods, not much importance can be attached to these results. It may be worth while to examine the question more extensively for a network of selected stations or selected areas in India, for settling this point conclusively. Evidence so far collected does not, however, support the possibility of any regular periodicity in Indian rainfall.

6. *Occasions of Unusually Heavy Rainfall*

The frequency of heavy rainfall over India has been discussed in a recent note by Doraiswamy and Mohamad Zafar (Scientific Notes, Ind.

TABLE 4. *Monsoon Rainfall, June to September. Inter-correlations between Pairs of Divisions. Period, 1875–1918*

(*Vide* Table E, Memoirs of the Ind. Met. Dept., Vol. **25**, Part ii, p. 23)

Division	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*XIII*	*XIV*	*XV*
I Burma	−0·47	−0·14	−0·05	−0·01	−0·09	−0·21	−0·29	−0·07	−0·26	+0·01	−0·01	−0·32	−0·15	−0·33
II Assam	..	+0·45	+0·27	+0·01	−0·16	−0·10	−0·13	−0·17	−0·24	−0·27	−0·40	−0·01	−0·11	+0·14
III Bengal	..	..	+0·56	−0·07	−0·07	−0·05	+0·04	−0·24	−0·31	−0·22	−0·45	−0·18	−0·15	−0·12
IV Bihar and Orissa	..	..	..	+0·31	+0·13	+0·06	+0·06	+0·05	−0·10	+0·04	−0·27	−0·01	−0·07	−0·16
V United Provinces	..	..	..	..	+0·49	+0·31	+0·06	+0·55	+0·30	+0·68	+0·33	+0·37	+0·07	+0·22
VI Punjab	..	..	..	..	..	+0·82	+0·56	+0·87	+0·59	+0·79	+0·59	+0·61	+0·11	+0·35
VII N.W.F.P.	..	..	..	..	..	..	+0·65	+0·73	+0·59	+0·64	+0·46	+0·63	+0·22	+0·45
VIII Sind	..	..	..	..	..	..	..	+0·50	+0·65	+0·34	+0·34	+0·40	+0·24	+0·40
IX Rajputana	..	..	..	..	..	..	..	..	+0·57	+0·81	+0·54	+0·57	+0·21	+0·40
X Bombay	..	..	..	..	..	..	..	..	..	+0·46	+0·58	+0·72	+0·53	+0·66
XI Central India	..	..	..	..	..	..	..	..	..	..	+0·61	+0·40	+0·05	+0·21
XII Central Provinces	..	..	..	..	..	..	..	..	..	..	..	+0·55	+0·07	+0·18
XIII Hyderabad	..	..	..	..	..	..	..	..	..	..	..	..	+0·38	+0·61
XIV Mysore	..	..	..	..	..	..	..	..	..	..	..	..	..	+0·80
XV Madras	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Met. Dept., Vol. 7, No. 77). With reference to the heaviest fall in a day, they find that:

(i) Falls exceeding 5 in. in 24 hours have occurred over the whole of India excluding NE. Baluchistan and parts of the NW. frontier.

(ii) Falls have not exceeded 10 in. in 24 hours over most of the interior of the Peninsula and of Burma and in a few districts in the Central parts of the country.

(iii) Falls of 15 to 20 in. in 24 hours have occurred all along the west coast including Gujerat and Kathiawar, on the south Coromandel coast, on the north Burma coast, in south Assam, in Bengal, and the foot of the Himalayas.

(iv) A few isolated falls of 20 in. and over have occurred in the plains.

(v) The greatest fall of over 40 in. in 24 hours has occurred at Cherapunji in the Khasi hills.

When heavy rainfall occurs consecutively on a number of days and particularly over the catchment areas of rivers, the magnitude of the ensuing floods may well be imagined. Ramkrishnan (Scientific Notes, Ind. Met. Dept., 7, No. 74) has estimated the total volume of water precipitated over certain areas in South India on days when they were under the grip of storms coming from the Bay of Bengal. The values given by him for one of these storms are quoted below:

Date	*Area on land which had rain of 0·5 in. and more in sq. km.*	*Volume of water precipitated on land in cu. km.*
21.10.30	60,150	1·9
22.10.30	53,730	1·6
23.10.30	71,540	4·9
24.10.30	103,660	8·0
25.10.30	133,740	6·5
26.10.30	141,620	7·1
27.10.30	342,520	11·9

Increasing forest-cover, checking erosion, delaying flood-peaks, and training the major rivers, &c., are problems which have begun to demand an increasing attention of the State.

7. *Regional Peculiarities in Distribution of Rainfall: Climatic Homogeneity*

Even if we divide the country into climatically homogeneous tracts, judging from the normal rainfall, there are still outstanding local peculiarities. This may be emphasized with the aid of a few examples.

Suppose that a weather forecaster expects a particular subdivision in the country to come under the influence of disturbed weather and forecasts rainfall over the area. Can he expect all the rain-gauge stations to record more or less similar rainfall during a particular day? Or will the rainfall be very variable? This involves the question of rainfall variability in space and is very important from the weather forecaster's point of view.

We may also consider the point of view of an irrigation engineer faced by the problem of constructing reservoirs to serve the agriculturist's needs. Should he construct one big reservoir at a likely place or should he scatter a series of small reservoirs, casting his net wide as it were, so that one or the other of the reservoirs collects such rain as may fall over its neighbourhood? How would the variability between stations in a given area compare with the variability between days of a month and with that due to random chance?

In connexion with a recent inquiry, the variability of rainfall in the month of July 1942 was analysed for a number of representative areas in India, taking 20 stations selected at random from each of these areas. Table 5 gives the analysis of variance between 'stations', 'days' of the month, and 'residual' (due to random variability), for the Punjab, the United Provinces, the Central Provinces, Bengal, Rajputana, and

TABLE 5. *Analysis of Variance of Rainfall in July 1942*

Due to	*Degrees of freedom*	*Sum of squares*	*Mean square (variance)*	*Standard deviation*	*Variance ratio: 'F'*	*Rainfall per day*	*Coefficient of variability (%)*
1. *The Punjab.*							
Stations	19	21·1334	1·1123	1·55	3·73•	0·228 in.	680
Days	30	19·8421	0·6614	0·81	2·22•	..	356
Residue	570	169·8981	0·2981	0.55	..	..	241
Total	619	210·8736	0·3407	..	..	..	..
2. *The United Provinces*							
Stations	19	16·1105	0·8479	0·92	1·55	0·466 in.	197
Days	30	114·5280	3·8143	1·95	6·97•	..	418
Residue	570	312·1042	0·5475	0·74	..	..	159
Total	619	442·7427	..	..	..	..	..
3. *The Central Provinces*							
Stations	19	45·5754	2·3987	1·55	1·35	0·697 in.	222
Days	30	270·4394	9·1465	3·02	5·16•	..	433
Residue	570	613·9953	1·7715	1·33	..	..	191
Total	619	929·9901	1·5024	..	..	..	..
4. *Bengal*							
Stations	19	41·4545	2·1818	1·48	3·62•	0·422 in.	350
Days	30	43·2902	1·4430	1·20	2·39•	..	284
Residue	570	343·4197	0·6025	0·78	..	..	185
Total	619	428·1644	0·6917	..	..	..	..
5. *Rajputana*							
Stations	19	108·8973	5·7314	2·39	6·92•	0·417 in.	573
Days	30	46·2551	1·5418	1·24	1·86	..	297
Residue	570	471·9398	0·8280	0·91	..	..	218
Total	619	627·0922	1·0131	..	..	..	..
6. *Malabar*							
Stations	19	85·4648	4·4981	2·12	5·53•	1·331 in.	159
Days	30	382·1749	12·7392	3·57	15·68•	..	268
Residue	570	463·1872	0·8126	0·90	..	..	68
Total	619	930·8269	1·5038	..	..	..	..

• Means significant at 1 per cent. level.

Malabar. Column (5) gives the standard deviation of the variability 'between stations', 'between days', and 'residual' or error. The next column gives the ratios of the variances, i.e.

$$\frac{\text{Variance between stations}}{\text{residual variance}} \text{ and } \frac{\text{Variance between days}}{\text{residual variance}}.$$

If the variability 'between stations', 'between days', and 'residual' are all of the same order of magnitude the ratio F will not be significant.

In the Punjab, Bengal, and in particular Rajputana and Malabar, the variability between stations is very significantly larger than that caused by random chance. In Malabar this variability is due to orography, whilst in Rajputana it represents a real climatic non-homogeneity. The variability between days is significant in all cases. In places like Rajputana it is indeed difficult to indicate where exactly rain would fall during a wet spell. The engineer would be well advised to construct a wide network of tanks in preference to a single big tank in such tracts.

8. *Irrigation Works and Large-scale Reservoirs, Bunds, &c.*

Wherever the precipitation falling over a very wide catchment is drained into large river-systems like the Indus and Ganges, it is obvious that irrigation projects will be successful, as has indeed happened in the Punjab and Sind. In the United Provinces, besides canal irrigation, tube-wells are also being sunk on a large scale.

It may be pointed out that the large dry tracts of Peninsular India which are not fed by rivers can get adequate supplies of water for agriculture if the necessary irrigation-projects are set up at suitable localities in the catchment areas of the Western Ghats *which receive sufficient rains for this purpose even in years with weak monsoons*. Much of this water is now drained by rapids flowing into the Arabian Sea. If large reservoirs are built up on the Ghats over elevated areas, taking advantage of natural facilities for impounding the rain-water, the water so collected can be fed into the plains to the east of the Ghats through canal systems. This is a problem which the State alone can tackle; it is full of large potentiality for the future of the arid tracts of Peninsular India.

9. In concluding this all too brief a summary of India's rainfall as affecting its agricultural potentialities, it may be appropriate to state that the India Meteorological Department is undertaking, in the very near future, to broadcast special weather bulletins and forecasts for the farmer. Seven Regional Forecasting Centres have been started. These will cater for the special weather requirements of their respective regions. Warnings for heavy and untimely rainfall, heat waves, cold waves, droughts, hail-storms, high winds, etc. will be issued, keeping in view the needs of the important crops of each region. In this new undertaking the Agricultural Meteorologist will maintain a close liaison between agriculture and meteorology.

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THE IMPROVEMENT OF SOIL FERTILITY[1]

PART I: GENERAL CONSIDERATIONS

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(*Imperial Chemical Industries: Central Agricultural Control*)

LESS than 10 per cent. of the earth's land surface is under cultivation,[2] whereas 30 per cent. has been reckoned as cultivable [2]. Yet it is generally agreed by those who have given most thought to the problem that only a small proportion of the land that remains is suited to permanent cultivation. Environmental conditions, including climate and relief, are such that most of the remaining land is best left under its present cover of grassland or forest. If cultivated, much of it is likely to undergo such rapid and destructive erosion that its fertility would soon be lost. The population of the world is still increasing—especially in the East—and the nutrition of most of mankind is far below the optimum in both quantity and quality [3, 4]. Indeed, a drastic world food-shortage is now at hand. Agriculturists have to face the fact, therefore, that more crop production is necessary from the existing cultivated land, and still more will be needed in the future. Increased crop production can be secured and maintained only if the fertility of the soil is also increased.

Most agricultural systems in the world are maintaining soil fertility at a low to moderate level only [1]; under some of them there is, indeed, a progressive loss of fertility as a result of soil exhaustion or erosion. On the other hand, modern intensive agriculture has proved capable of raising average crop yields to a level from two to four times those of the traditional or extensive systems; and it maintains the fertility of the soil at this higher level. At first glance, therefore, it might not seem too difficult to secure the increased crop production which the world needs by applying modern intensive methods more widely than at present.

In addition to mechanical improvements the methods of modern intensive agriculture include crop rotation, improved crop varieties, control of weeds, pests, and diseases, also two matters of especial importance for maintaining soil fertility: (1) combining arable cropping with the use of live stock, as in mixed farming or alternate husbandry; (2) using inorganic fertilizers to supply soil deficiencies and to supplement local organic manures. Although many of the technical details are modern, the broad principles are old and well tested by experience. Even inorganic fertilizers have been in continuous use for over a century.

[1] The second of two papers dealing with various aspects of soil fertility; the previous paper [1] should be consulted for more detailed information about the maintenance of fertility under existing systems of agriculture.

[2] An estimate made by the writer from the data of the *International Year-book of Agricultural Statistics*, 1938–9 (Rome), and of J. L. Buck's *Land Utilization in China*, with an allowance for land cultivated by populations not included in these sources, gave 8 per cent. as the proportion of the total land area that is cultivated.

It is the wider application of these methods that is lacking. So long ago as 1787, George Washington wrote to Arthur Young: 'Very few persons have attended to sowing grasses, and connecting cattle with their crops. A half, a third or even a fourth of what we mangle, well wrought and properly dressed, would produce more than the whole under our system of management; yet such is the force of habit that we cannot depart from it' [5]. Not only does a system of agriculture based on the foregoing principles best maintain soil fertility, and thus give the greatest production of crops over a long period, but it also leads to the production of a well-balanced human dietary, rich in protective foods; and it gives a system of farming which can provide a high standard of living for those on the land.

The problem of extending the methods of modern intensive agriculture to the rest of the world is, however, not a simple one. There are human difficulties, depending on habit or tradition, and on poverty, ignorance, and lack of health and energy. There are also natural difficulties: the methods of modern intensive agriculture were first worked out in humid temperate regions, and it is as yet uncertain to what extent they can be applied in other parts of the world. None the less it should be possible to adapt the methods to suit new conditions, while observing the principles of soil-fertility maintenance already found to be successful. The present paper is particularly concerned with examining the extent to which these principal methods of fertility maintenance can be applied in different environments.

Goals and Limits in Crop Production

To prevent complacency, even in our appreciation of the results of modern intensive agriculture, and to provide a goal for our efforts, we may inquire what level of crop production can be considered a sign of really high fertility. Very high crop yields have been obtained under glasshouse conditions, even in a sunless climate: for example, 50 tons per acre of tomatoes are commonly secured in the English glasshouse industry and larger yields are obtained under experimental conditions [6]. In the field, also, the maximum crop yields recorded are much higher than might be expected from the results of ordinary good farming. Thus an official survey in the U.S.A. [7], covering two years only, gave the following maximum verified yields in bushels per acre, obtained on not less than an acre of land: wheat 117, barley 112·5, oats 183·7, maize 174, and potatoes 790 bu. or 21·2 long tons per acre. In a competition, 239 bu. of maize were obtained [8]. Similar high yields of wheat and oats have been recorded elsewhere, for example in New Zealand.

Such high yields undoubtedly refer to especially favourable conditions. None the less, they show what is actually possible in the field; and they may stimulate agricultural scientists to wonder why, with the increasing power of science over nature, we should not approach these levels more often. What factors are chiefly responsible for most farm yields being so far below the maxima? Climate, particularly temperature and water-supply—neither too much nor too little—must be an over-

ruling factor, since high yields approaching those quoted are obtainable with many fertile soils under glass or with irrigation.

Another, no less important, factor is the supply of soluble, inorganic plant-nutrients. Where these are abundant, and climatic factors are not limiting, the highest yields of all are obtained, as in the commercial system of solution or sand culture known as 'hydroponics' [9]. By this system, yields at the rate of 200 to 300 short tons of tomatoes and 2,465 bu. or 66 long tons per acre of potatoes have been obtained [10]. Experience with hydroponic methods has also shown that in cloudy northern climates a deficiency of sunlight may limit the yields of some crops to a level not greatly above those obtained in soil, whereas in sunnier climates much greater yields are secured [11].

In connexion with the limiting effect of sunlight on crop yields, it should be noted that the greatest amount of solar energy, in summer, is received not at the equator but in a belt between about 23° and 35° N. or S. latitude [12]. This is because the sun is near the vertical for a greater number of days, and the summer days are longer, in this belt than over the equator. The fact may help to explain why, other things being equal, rice yields tend to be higher in the sub-tropics than near the equator. In the far-distant future, with cheap sources of energy and a sufficient water-supply, the greatest crop production may be obtained by hydroponic methods in the deserts that occupy much of this belt.

The question then arises, if we were able more widely to overcome the limiting factors that exist even in good agriculture, and to obtain such high yields as those mentioned, whether they would be economic. They generally would not, with ordinary crops under our present price-structure. The law of diminishing returns operates powerfully at such high yield-levels. Some further improvement is practicable, even in modern intensive agriculture [13], but it would be easier, and relatively less expensive, to raise the low yields of primitive or traditional agriculture towards those of modern intensive agriculture, rather than to push the latter much farther in the direction of the recorded maxima.

The Reclamation of Waste Lands

There are still large areas of land that are agriculturally waste or unproductive but are yet capable of improvement. However, only to a limited extent will the continuous cultivation of such land be possible. Much of the waste or unoccupied land of the world is, as already remarked, unsuited to agriculture, and it should remain under forest or grass. Improvement here would aim at bettering the existing vegetation cover rather than at replacing it by cultivation.

Broadly speaking, only level or nearly level land should be brought under simple cultivation in the future; gently sloping land may be cultivated where it is quite certain that adequate soil-conservation practices will be carried out; if steeply sloping land has to be cultivated, it should first be bench-terraced. Much of the uncultivated level land in the world will require drainage or irrigation before it can be made productive, but the extent of possible further irrigation is severely limited by topography and by water-supply. There are also areas where the fertility

of the soil is chiefly limited by plant-nutrient deficiencies, and this land will be relatively easy to reclaim through the use of fertilizers, including lime, where acidity is severe. Some of the waste lands of south China are of this type, and there are large areas similarly nutrient-deficient in the south-eastern U.S.A. and in many other countries. Where such soils are moderately hilly they can be reclaimed as improved grassland, rather than for cultivation.

The largest areas of unreclaimed land suited to permanent agriculture are probably the basins of some of the great rivers of the tropics, such as the Amazon and the Congo, where there are vast tracts of swampy or badly drained land difficult to cultivate for ordinary dry-land crops, but able to grow rice well if cleared and adequately fertilized. It may require generations or centuries yet to clear the jungle, control disease, and colonize these lands, but one can envisage them as being eventually no less productive than the valley plains of the Yangtze, the Irrawaddy, or the Ganges.

Some Technical Aspects of Soil Improvement

Most of the technical matters involved in increasing soil fertility are adequately covered in the text-books, but certain aspects emphasized by the writer's recent experiences seem worth recording.

(*a*) *Survey and investigation.*—Detailed soil surveys are essential in any complete scheme for improving soil fertility; but in making a preliminary study of an area there may be time for no more than a rapid reconnaissance survey. Over large areas the writer has found that Robinson's conception of soil suites may usefully be applied, if the definition is broadened to include mention of the great soil group, i.e. a *suite* (so defined) includes all soils within a great soil group formed from the same or similar parent material [14, p. 27]. In most parts of the world the geological formations are readily identified, and much geological mapping has been done; a useful map showing the major differences that are important in agricultural planning and in soil-fertility improvement may be constructed, after a rapid field survey, by observing the nature and distribution of the great soil groups, and mapping their subdivisions largely on a basis of geology. The topography or relief is also kept in mind: it is often closely correlated with the geology, and it influences the distribution of the great soil groups.

The mapping of soil fertility or of land-use capability (a concept closely related to soil fertility) is being undertaken now in several countries, including the U.S.A. [15] and New Zealand. There is often difficulty in relating the finer subdivisions of orthodox soil surveys to fertility or productivity status, although much work is now being done on this problem [16]. However, the broad subdivisions, such as great soil groups or suites, usually show a clear relationship with productivity and nutrient deficiency. The systems now being worked out in practice, for surveying soil fertility or land-use capability, generally pay considerable attention to relief: for example, the proportion of sloping or level land, the steepness of slopes, the freedom or otherwise of drainage. These are intensely practical matters which were not always

stressed in the older soil maps, but they make all the difference to the fertility of the soil and to the best methods for its utilization and improvement.

In planning land-improvement the nutrient deficiencies and fertilizer requirements of the soil must be known. A vast amount of time and effort has been expended on laboratory and glasshouse methods for testing soils; they have their uses, but still nothing can take the place of fertilizer field experiments as the final court of appeal. The field experiments must be well designed (e.g. factorial 'NPK Tests'), numerous, covering the chief crops, and repeated over a number of seasons, usually on a fresh site each season. Such a method of 'soil testing' gives complete and positive information, as well as affording a demonstration of the value of fertilizers, which cannot be obtained in any other way. If the experimental programme can be planned from the beginning as a 'soil-fertility investigation' (as was done in China during the war [14, p. 132 et seq.]), its results will be more informative and more easily brought together than will the results of an even larger number of haphazard, unplanned experiments.

(*b*) *Manuring*.—In recent years the long-dormant opposition to the use of artificial or inorganic fertilizers in agriculture has been revived, by Howard and others [17, 18]; their case has been presented with an almost religious fervour; it has made some popular appeal, and it cannot be ignored in discussing methods of soil-fertility improvement. The arguments put forward have been answered by agricultural scientists as well as by practical farmers [19, 20, 21, 22]; the writer does not propose to enter the discussion, except to clarify his own attitude to the problem. Briefly, he holds that it is wrong to set up an artificial opposition between organic manures and inorganic fertilizers: where possible we should use them both. Not 'organics *versus* inorganics', but 'organics *plus* inorganics'.

There are many soils which are, by nature, seriously deficient in major or minor nutrient elements; there is also a continual drain on the soil for these elements, which are removed by leaching, by crops and live stock, and by fixation; a system of farming based on local organic manures alone, as in China [1], works in a closed cycle which makes it impossible to replace these deficiencies fully or to raise average yields beyond a moderate level; maximum yields can be secured only by bringing in more plant-nutrients from outside in the form of inorganic fertilizers. The organic-matter content of the soil should also be maintained by all possible means, including the use of organic manures or grassland farming; inorganic fertilizers themselves often help to maintain organic-matter supply by producing more crop residues, larger green-manure crops, and better grassland.

It is only in this way that the high yields and high soil-fertility levels of modern intensive agriculture have been obtained. Without inorganic fertilizers, as recent war experience in Europe has demonstrated only too clearly, yields fall and high soil fertility cannot be maintained. Whilst the unwise use of inorganic fertilizers may damage soils and crops, so may the unwise use of organic manures. There is no evidence

that when inorganic fertilizers are correctly employed, along with organic manures or other sources of soil organic matter, and lime if necessary, they can do anything but good. To secure the increased food production which the world vitally needs, we *must* use inorganic fertilizers. The problem is not whether to employ them but how to use them in the best way.

It was well said some years ago: 'The full possibilities of humus will only appear when the dressings of compost are supplemented by the addition of suitable artificials. The combination of the two, applied at the right moment and in the proper proportions, will open the door to the intensive crop production of the future. Humus and artificials will supplement one another' [23]. Howard has changed his views since he wrote this, but the advice remains good.

The opposition to inorganic fertilizers has come from a group of people who advocate composting to the exclusion of almost everything else. However, practical experience and scientific experiment alike have shown that there are many other good sources of soil-organic matter besides compost, and the choice must be made, not on doctrinaire grounds, but on a basis of economics and of convenience under local conditions. Among these sources may be mentioned temporary grassland, especially ley farming; farmyard or stall manure; crop residues turned under (green residues can be used directly, whilst straw or other mature residues may require to be supplemented by a nitrogenous fertilizer [24]); leguminous green manuring; wild herbage, including bracken and the twigs of shrubs, preferably in the green condition; and sewage sludge [25, 26]. Among composts there are not only Indore compost [23], but other types [27] including artificial farmyard manure ('Adco'), composted town refuse [28], and sewage sludge composted with straw [29]—this last is a very promising source of organic manure under the conditions of modern civilization. It should be noted that where a material contains active or readily available nitrogen, composting it often leads to a loss of some part and immobilization of another part of the nitrogen: it may be better to use such material directly as manure rather than to compost it.

Little can be said here about the actual technique of manuring, important though it is for increasing soil fertility and crop production (recent developments are described in [30]). The needs of the particular soil as well as the particular crop being manured have to be kept in mind. For efficiency in using the limited quantities of manures and fertilizers available to agriculture, we should apply them first to the most deficient soils, and avoid over-heavy applications, especially of plant-nutrients that are already plentiful in the soil. It is here that soil tests by both chemical and biological methods (including field experiments) are most valuable. The accuracy of existing methods of soil testing still leaves much to be desired, but the methods at least indicate the existence of a marked excess or deficiency of a plant-nutrient.

Another matter of importance, and one in which there has been a rapidly growing interest in recent years, is the existence of serious deficiencies or excesses of minor elements (not NPK) in soils. Some of

these elements are beneficial, for either plant or animal nutrition, and some are harmful [31]. As the scientific study of agriculture extends in various parts of the world more examples of these minor-element effects are likely to be met with, and they should especially be guarded against where heavy applications of NPK fertilizers or lime are employed on sandy or peaty soils. There are useful books on the identification of major- and minor-element deficiencies by their symptoms or effects on plant-growth [32, 33]. Yet another matter important in practice is the placement of fertilizers in relation to seeds or crop rows: good placement sometimes increases the effect of a fertilizer application to a surprising degree.

(*c*) *Soil conservation* is of the first importance for maintaining or increasing soil fertility. The serious decreases in fertility that are caused by erosion have been referred to [1]; methods of soil conservation appropriate to different climatic conditions will be mentioned later. For details, readers must again be referred to the standard works on the subject [34, 35]. In recent conservation practice more emphasis is being placed on checking run-off and erosion where it begins—by land-use planning and contour farming—than on engineering works to control the effects of erosion at a later stage.

Soil-conservation measures often require radical changes in land-use, and this may involve the complete withdrawal of some land from cultivation. The general principle is that of 'zoning' the land, according to its degree of slope, soil characters, &c., so that, broadly speaking, only flat land and very gentle slopes will be cultivated without especial soil-conservation measures; moderate slopes may be cultivated only if adequate soil-conservation precautions are taken; steeper slopes are not cultivated at all, but are kept under permanent grass; and the steepest slopes may be used only for woodland or forest [15]. The exact degree of steepness of slope which is admitted to each class of 'land-use capability' varies according to soil properties and climate. Details in the application of this type of controlled land-use will evidently vary greatly, but the general principles are important and should be kept in mind in all future planning of agricultural development, the reclamation of waste lands, and so on.

Although some land may have to be taken out of cultivation when planning for soil conservation, the fertility of the land remaining under cultivation is simultaneously increased and preserved: in the long run this will be more than sufficient to offset any loss of crop through ceasing to cultivate other land. Already in the U.S.A. thousands of farms have been operating under soil-conservation measures, for periods up to ten years or more, and it is becoming possible to make actual estimates of the gains in yield due to conservation methods under ordinary farming practice. Some farms, where erosion had gone particularly far, have recorded increases in production of 100 per cent. or more; a 30 or 40 per cent. increase in yield is common [36]. Taking the average of 9,000 farms, all over the U.S.A., farmed by good, bad, and indifferent farmers the average increase in production was 33 per cent. (W. C. Lowderm'ilk, private communication). This figure may be

expected to become larger as conservation methods further increase soil fertility; it is only a beginning, yet it already represents a large increase in total crop production; and—what is more important—on all these farms the previous tendency for soil fertility to be lost has been transformed into a steady gain in fertility.

Since much of the land which is taken out of cultivation in conservation farming is put under grass, it can be made productive in its own way through the use of live stock; and, indeed, the resultant increase in animal products will be beneficial both to soil fertility and to human diet. It may be noted that many of the practices advocated for soil conservation in the U.S.A. (in addition to contour farming), such as crop rotation, organic manures, the use of fertilizers to supply soil deficiencies, leguminous cropping, and more grassland farming, are also features of modern intensive agriculture as carried out, say, in north-western Europe.

There are two main ways of improving soil fertility: irrigation and manuring, whose relative importance depends on whether the factor chiefly limiting crop growth is moisture supply or nutrient supply. The effect of irrigation in improving the moisture supply of an arid soil is dramatic, and its value is universally recognized. Most governments in drier areas are ready to undertake irrigation schemes, even though they may be very expensive and may require years for their completion.

The effect of manuring, where it supplies plant-nutrients to soils seriously deficient in them, is no less dramatic than that of irrigation, but its full value is scarcely apprehended as yet by many non-technical people. The writer has seen, for example, extensive tracts of waste land in south China where fertilizers made all the difference between failure and success of the crops; in New Zealand he has seen large areas of formerly poor, unhealthy pastures now made richly productive by fertilizers; and in the area of the Tennessee Valley Authority the great success of the soil-conservation and land-reclamation work depended on 'the almost magic mineral, phosphate' [37]. There are many other parts of the world where the use of fertilizers will likewise be the key to the reclamation of poor, waste, or abandoned land. What is more, manuring where it is needed is easier and cheaper than irrigation, and quicker to bring results. Yet authorities planning land reclamation and resettlement, or attempting to increase human food supplies, are still prone to overlook fertilizer supply as a first requirement and to think in other terms.

For fully effective fertility improvement each locality requires individual consideration, with a complete background of knowledge of the geographical and agricultural features, including the nutrient status of the soil. Looking at such problems on a world-wide basis, however, it is possible to see a fairly clear relationship between climate, particularly rainfall, and the methods that should be adopted to maintain or increase soil fertility.

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THE IMPROVEMENT OF SOIL FERTILITY

PART II. RELATIONSHIPS WITH CLIMATE

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(*Imperial Chemical Industries: Central Agricultural Control*)

BEARING in mind the general considerations outlined in Part I, we will now study in more detail the relationships with different types of climate, for climate is the factor which has the greatest influence on the methods of fertility improvement that should be adopted. The account that follows does not attempt to consider all possible climates, but only those types which seem most important in relation to soil-fertility improvement, namely: (1) very low rainfall; (2) moderately low rainfall; (3) moderate rainfall; (4) heavy rainfall, (*a*) in temperate, (*b*) in tropical, zones. To express the limits of these types in precise numerical terms would be difficult, because the effectiveness of precipitation varies with temperature, latitude, altitude, cloudiness, and the presence or absence of marked dry seasons [38, 39]. However, something is said in the description of each type of climate to give a clue to its limits.

There are genetic soil types or great soil groups that correspond with these climatic types. Without entering into detail it may be said that pedocal soils are mostly found in climatic types (1) and (2); pedalfer soils in types (3) and (4). Some relations between these soil groups, nutrient supply, and fertility maintenance were mentioned in the first paper [1].

1. *Very low-rainfall* (*arid and semi-arid*) *areas.*—Forests will not grow or thrive in these, so that the most desirable system of land utilization is grassland (which, in fact, occurs naturally in many such regions). The grazing of cattle, sheep, and other live stock is the best way of making the soil productive, yet great care has to be taken to avoid overgrazing. Overgrazing leads to deterioration or destruction of the soil cover, which will be followed by wind and water erosion just as serious as that following injudicious cultivation.

Cultivation may be possible in moist years, but to go by this is misleading and dangerous, because series of drought years are certain to follow, a great variability in annual rainfall being typical of semi-arid regions. During drought years crops will fail and soil drifting is likely to occur: this leads to 'dust-bowl' conditions, or 'man-made deserts' [1]. Permanent unirrigated cultivation would be possible in such areas only with very careful attention to, and maintenance of, measures for soil and water conservation. The value of the crops obtained is not likely to be sufficient to make this financially practicable, except possibly in small fields under such systems as the 'pebble mulching' employed in NW. China. Apart from this, soils cultivated for ordinary field crops under such dry conditions will not in practice receive the treatment necessary to preserve their fertility, and it would be better for the community that they should not be cultivated at all. Measures to ensure

this, by compelling farmers to change from arable to grassland farming, are being adopted, for example, in the *mallee* scrub areas of southern Australia, and in Canada.

Where wind or water erosion has already occurred, measures of soil conservation include severe restrictions on land-use; sowing or planting grasses and other plants selected to withstand the drought conditions; planting rows of trees for windbreaks; adopting controlled grazing to preserve the vegetation cover; and using gully control and levelling, check dams and storage dams, diversion dams, and other such engineering practices to bring under control any dangerous degree of gully erosion, as well as to improve the water-resources.

Irrigation is, of course, the best method of improving soil fertility in dry areas, where topography or water-resources make it feasible, and under favourable conditions it will make extremely heavy yields possible. The rather high capital cost of irrigation often leads to a concentration on cash crops of high economic value, e.g. fruit trees, vines, tomatoes, vegetables (for drying or quick-freezing), cotton, or sugar-cane, but for the good of the community it may be desirable to emphasize the need for growing more of the ordinary food crops (especially in Asia); and it will benefit both human nutrition and soil fertility if live stock also are raised. Mixed farming is both possible and desirable on irrigated land. Heavy crops of lucerne and other fodder crops are obtained by irrigation; good pastures are also possible, on which, as in Australia, dairy cattle or fat lambs may be raised. Paddy rice requires so much water that it is not widely grown in irrigated arid regions, but where the water can be afforded very high yields may be obtained, as in Sind, Australia, and southern California.

The benefits of irrigation are realized everywhere; what is not so well realized is its dangers. Almost every large irrigation project in low-rainfall areas has had serious trouble with rising water-tables, water-logging, and the formation of alkali or saline soils. These, if they become serious, will completely destroy the productive power of the soil. The ideal would be for a deep drainage system to be installed as a part of every irrigation scheme; but the extra expense involved would doubtless discourage the promoters of such schemes, and the question of drainage usually has to be left until waterlogging and salinity problems have become too serious to ignore.

Salinity is, indeed, the great menace to soil fertility in irrigated dry areas, and still more potentially valuable land is likely to go out of production before the problem has been conquered. On calcareous soils where drainage is possible, the cure is simple: deep drainage, and irrigation with water low in salt-content (to wash the salts out of the soil) is sufficient. Such reclamation is standard practice in Egypt, in the northern part of the Delta; in Mildura, Australia, also, land once made sterile by alkali following irrigation has been reclaimed in this way. Where drainage is difficult or impossible, as in basins or low-lying situations, a complete cure may not be secured, but growing a crop like rice may help by diluting some of the salts or washing them away. On soils low in calcium, once a sodium clay has been formed its reclamation is possible

only with the help of dressings of gypsum or other calcium compounds, and these are likely to be expensive or difficult to secure. Unless a large volume of water is being employed deliberately, to wash salts out of the soil, it is desirable to cut down to a minimum the amounts of irrigation-water applied to the land. Routine observations and tests for moisture at various depths should be made before using the water, in order to decide whether irrigation is needed, and if so, how much.

Much important research work, including soil surveys of great practical value, has been carried out in such major irrigated areas as the Punjab, the Sudan, interior Australia, and southern California [40, 41, 42, 43, 44].

Most irrigated soils of dry regions are naturally rich in plant-nutrients, especially phosphate and potash; manuring is less generally needed than with soils of wet regions, and a moderate dressing of nitrogen may be all that is required. However, some irrigated soils show striking nutrient deficiencies, due to deficiencies in the parent rocks from which the soils have been derived: for example, phosphate, or zinc. The soils or growing crops then need treatment with the missing element or elements. One crop may be more sensitive to such a deficiency than others, e.g. citrus to zinc- or legumes to phosphate-deficiency. It should be noted that phosphate may give good results with legumes (cover crops or green manures) even when it does not appear to be needed by other crops.

In the past organic manuring for irrigated crops has not received much attention, because one of the chief functions of the soil organic matter—that of regulating the soil moisture-supply—is already ensured. However, irrigation often tends to harm the texture of the soil, through the introduction or washing-down of clay particles transported by the irrigation-water. Salinity will accentuate this trouble, and also destroy the soil structure. Thus there is much to be said for taking all possible steps to add organic matter to the soil, whether by green manuring and cover cropping, the use of composts, or the keeping of live stock and the use of their manure. Where saline or alkali soils have to be reclaimed, organic manures may be of great assistance.

Fortunately, since irrigated soils are almost always level or terraced, soil erosion and conservation is not a serious problem. Care may, however, be needed to prevent the damaging of valuable irrigated land by gravel or silt washed down by erosion occurring elsewhere. Many of the ancient irrigation-systems of the world have come to grief because of the silting-up of intakes and canals.

2. *Moderately low-rainfall* (*sub-humid*) *areas.*—There is no sharp line between these and the semi-arid areas of the preceding type, but the class is intended to include areas where the rainfall is high enough to allow the continuous cultivation of such crops as wheat, maize, millets, or sorghum, with only rare crop failures due to drought, although yields may often be limited by water-supply. 'Dry-farming' precautions are necessary, at least at the lower rainfall end; and certain cultural practices are found beneficial in this group which may be less beneficial or even disadvantageous under moister conditions. This class, like the last,

includes chiefly soils and regions under a natural grass vegetation—steppes, prairies, or savannahs—although trees grow fairly readily if they are protected from fire or other damage.

Where the land is farmed under grassland systems, ranching is usual; and whether it is grazed in this way or by peasant proprietors (as in India, North China, and Africa), care is necessary to avoid overgrazing. With overgrazing, severe erosion may take place, rendering the land almost useless, so that controlled grazing is one of the first conditions of maintaining fertility. This may also require the use of some irrigated or other arable land to produce fodder crops and so protect the grazing land from overgrazing in bad seasons.

For arable cultivation, irrigation is still beneficial where topography and water-supply permit; much higher average yields can be obtained with its help than without it, even though the benefit may be less apparent in occasional moist seasons. With irrigation, drainage will usually be necessary in order to avoid damage from rising water-tables or soil salinity, although the natural rainfall is sometimes high enough to prevent much salt accumulating in the soil. The irrigated soils often respond well to nitrogen; other elements may occasionally be necessary when deficient in parent materials.

Without irrigation some dry-farming methods are needed. At the lower end of the rainfall range it may be possible to grow only one crop in two years or two crops in three years. Other crop rotations, including the use of legumes, and green manuring, may cause trouble through the extra transpiration to which they give rise, depleting the soil-moisture reserves and leading to failure of the main crop.

On the whole, fertilizers are not so effective as in wetter regions; nitrogenous manuring may even be dangerous (if rainfall is very low and there is no irrigation) by producing so large a young crop that it transpires more water than the soil can supply, causing crop failure later. Under such conditions a crop that looks poor at first may eventually do better, and give a better yield than one that looks fine and heavy in its young stage, but that fades out later for lack of water. Soils of these low-rainfall areas, being little leached, do not usually lack phosphate or potash, and these fertilizers generally need not be used; but some soils occur, notably in Australia and South Africa, in which the parent materials were deficient in phosphate or other nutrient elements, and manuring with these elements has been very effective.

At the higher end of the rainfall range, approaching the moderate rainfall type, there may be a useful response to nitrogen even without irrigation, especially in areas where the soils have a high phosphate-status (whether this is natural or the result of long-continued fertilizing with phosphates). Thus the use of fertilizers with soils of moderately low-rainfall regions is a particularly complex matter, and one in which constant control by well-planned field experiments is essential.

Temporary leys, using special herbage mixtures suited to the low-rainfall conditions, are also proving useful in raising the fertility of such soils [1], and their use should be extended. In fact, mixed farming or alternate husbandry is likely to spread even through the regions of

moderately low rainfall, as its benefits become appreciated; there, however, it is rather more difficult to introduce at first, than in the moister regions.

Farmers in drier regions have usually been able to do little to maintain the soil organic matter, because with extensive agriculture it is not economic to use manures, either natural or artificial, and in any case they are usually not very effective in their immediate action on crop yields. Organic manures are sometimes said to be preferable to artificial fertilizers in such areas, perhaps because their use involves less chance of damage from excess nitrogen; but they do improve soil structure, so assisting the infiltration of rain-water and resisting wind or water erosion. They may consist of compost, cattle manure, or green manure, but if it is very dry the slow decomposition of structural organic matter is troublesome.

Another method which has attracted attention recently is that of 'sub-surface tillage'. There is a growing school of thought which claims that under rather dry climatic conditions, ploughing—and especially deep ploughing—is undesirable or even harmful, because it interferes with desirable moisture movements in the soil, promotes erosion, and accelerates the breakdown and loss of soil organic matter [45].

Various systems are being worked out to obviate ploughing, and to provide a 'mulch' of organic residues on the soil, so promoting infiltration and resisting erosion, particularly by wind. Their common feature is what might be called skimming or shallow machine-hoeing, along with the use of special cultivators, rollers, drills, and other implements, which will leave the crop residues, stubbles, and weeds on the surface or only partly buried [46]. It is claimed (contrary to expectation) that these cellulosic residues do not seriously compete with a growing crop for nitrogen—perhaps because they remain near the surface and only decompose slowly. Experiments have shown that in some localities (e.g. in Nebraska) the system definitely reduces run-off and erosion, promotes infiltration, and leads to higher yields.

These results were, however, obtained under rather special climatic conditions, including prolonged dryness so that weeds hoed and left on the surface withered and died, instead of rooting again. The same methods, tested in areas with a higher rainfall, or where conditions are otherwise more suited to weed-growth, and where crop yields are less limited by water-supply, have actually depressed yields in comparison with standard methods of cultivation, instead of raising them. Thus sub-surface tillage is not an agricultural panacea, as Faulkner claims [45], although the method undoubtedly has promise under suitable conditions.

Where sloping land is cultivated in regions of rather low rainfall, severe gully erosion often occurs, as well as sheet erosion. Gullying is the more troublesome because the natural regeneration of vegetation is slow under such dry conditions; though the total precipitation is low, what rain there is falls in intense showers. Indeed, it is in these regions throughout the world that erosion is the most serious menace to soil fertility and to food production, and that soil conservation is particularly necessary. The chief conservation methods in moderately low-rainfall areas include land-use zoning, bench-terracing where sufficient labour is

available, broad-based terraces on gentler slopes, contour cultivation, and strip-cropping. By using methods such as these, as well as damming large gullies and levelling old gullies by bull-dozers, some very striking reclamation of land once devastated by gullying has been carried out, as the writer recently saw in Nebraska. Here, land which a few years ago was so badly gullied as to be uncultivable has been brought back into production, and is now giving good crops; at the same time a new and fertile soil is being built up.

3. *Moderate rainfall (humid) areas.*—This type merges into the last one in regions of light-to-moderate rainfall; it may be distinguished on the basis that there is enough rainfall in normal seasons so that moisture deficiency does not appreciably limit crop-growth. Soils of humid areas have undergone some degree of leaching, and they tend to be naturally deficient in plant-foods and lime; manuring is consequently more generally effective than with the previous types. Drainage is likely to be needed in low-lying areas, and on the whole drainage replaces irrigation as the principal method of ameliorating soil-moisture conditions.

In temperate climates these are the areas where soil fertility has been most successfully raised to high levels by using modern intensive methods of farming, and which offer most scope for the ready extension of these methods in the future. In some localities, mixed farming or alternate husbandry is already widely employed; elsewhere, monocultures tend to dominate farming: either the culture of cereals or cotton, as in the U.S.A. and the U.S.S.R., or of grassland, as in New Zealand. There is some tendency in temperate humid climates for arable farming to predominate at lower rainfall- and grassland farming at higher rainfall-levels.

In contrast to the low-rainfall areas—types (1) and (2)—grazing can be carried out intensively in humid climates without danger of causing erosion through overgrazing, provided that the grassland is well manured and well managed. With the help of fertilizers needed by the soil, of the legumes in the pasture, and of the return of nutrients to the soil through the animal excreta, well-managed grassland under these conditions can build up soil fertility at a noteworthy rate [1]. A good grass-cover is also one of the best methods of erosion control on moderately sloping land, and hence of soil conservation. It promotes soil fertility and the infiltration of rainfall by raising the organic-matter content of the soil, and notably by improving the structure [47, p. 42].

Consequently, from the point of view of increasing and maintaining soil fertility in humid regions, there is much to be said for farming systems that combine both grassland and arable farming: both animal and crop husbandry. The method chiefly coming into favour in NW. Europe is that of ley farming or alternate husbandry [1, 47]. In the U.S.A. soil-conservation practices often require the interposition of a strip of grassland among strips of different arable crops in contour farming. Owing to fencing problems, this grass strip is not usually grazed, but it may be cut for hay or silage, and fed to animals whose manure will later be spread on the land. In the U.S.S.R. also, a much greater use of grassland is being advocated, especially to improve soil structure.

Developments along such lines as these, worked out to suit the needs and conditions of each locality, are likely to offer the greatest hope of soil-fertility improvement in the future.

The aim should be to include legumes with the grass-seeds mixture, in order to make use of their ability to fix atmospheric nitrogen. The establishment and maintenance of legumes often require the liming of acid soils, and the manuring of phosphate-deficient ones: hence the success of the system 'lime, phosphate and legumes' in the T.V.A. [37], and elsewhere in the U.S.A. The conditions needed to maintain a good grass-legume herbage are by now fairly well worked out in humid, temperate climates, but many obstacles still remain to be overcome in hotter or drier climates: notably the selection of suitable legume species [48]. To solve this problem is, indeed, one of the most urgent matters in improving soil-fertility maintenance in the hotter parts of the world, and one that deserves every attention. In the tropics organic matter disappears so rapidly from the soil that ordinary applications of bulky organic manures may not be effective in increasing the soil organic matter, whereas grasses can do this [49].

In the past, before the value of alternate husbandry was appreciated, mixed farming (arable farming supplemented by live stock, which might either be grazed on fields of permanent grassland or fed on crop by-products and on hay or fodder crops) appeared to be the most successful basis for maintaining soil fertility. Rigorous comparisons have not yet been made over a wide enough range of conditions to decide whether mixed farming or alternate husbandry is to be preferred: possibly, in the end, it will be found that one system is better, say, under rather drier conditions and the other under a rather more humid climate. Meanwhile, mixed farming can be adopted in any moist climate, either temperate or tropical, for suitable fodder plants or pasture and meadow grasses of some kind can always be grown: thus to secure the benefits of animal husbandry for soil-fertility maintenance need not await the working out of successful systems of alternate husbandry. Whether by the one system or the other, modern intensive agriculture on the basis already described [1] can, and should, be developed in all regions of moderate rainfall.

Owing to the tendency for the soils to be leached and deficient in plant-nutrients, the improvement and maintenance of soil fertility under humid conditions depends as a first essential on the wise use of inorganic fertilizers. These are needed by arable crops to make good existing nutrient deficiencies and to counterbalance further losses; good new grassland cannot be established without them; and when old grasslands are ploughed up, they are often found to be deficient in phosphate and lime, which must be applied for the sake of the arable crops that follow [30].

For efficiency in the use of fertilizers it is very desirable to ascertain (by field experiments and laboratory tests) what nutrients and correctives are most needed by the soil, and hence to 'manure the soil' as well as the crop. The older custom, of using, say, a 'corn manure' or a 'potato mixture' or a 'cotton mixture', is an inefficient one unless the mixtures

take into consideration the needs of the local soils. Often a single nutrient or a mixture of two will supply all that the soil needs.

Except where alternate husbandry is practised, when the grassland turf supplies organic matter, inorganic fertilizers should not be used to the exclusion of bulky organic manures, but rather as a supplement to them. In humid climates, precautions must be taken against acidity developing or being accentuated, by the regular use of lime on acid soils. Where lime is too difficult to obtain or too expensive to apply regularly, non-acid-forming fertilizers and fertilizer mixtures are to be preferred.

Minor-element deficiencies tend to be more serious and widespread under humid than dry conditions, because of leaching. The deficiencies occur especially often in sandy soils, which are most readily leached, or in peaty soils that are low in mineral matter; soils derived from acid igneous rocks tend to show them; podzolization is often a sign that minor-element deficiencies are to be suspected. Boron, magnesium, manganese, zinc, copper, cobalt, and molybdenum are some of the deficiencies that have been recorded; where they occur they may seriously limit healthy plant or animal growth, or both [31]. Fortunately they are easily remedied, once the cause has been identified, by small applications of the deficient element. This is often applied in admixture with other fertilizers, as in cobaltized superphosphate, and in this way land previously valueless has been cheaply raised to high value and to great productivity. Striking results have thus been obtained in the U.S.A., Australia, New Zealand, and western Europe; and doubtless many other instances of such deficiencies remain to be identified, and cured, in less developed countries. Dangerous excesses of toxic elements may also occur: e.g., fluorine, selenium, and molybdenum [50].

Some minor-element deficiencies are accentuated by liming: heavy liming of leached soils should therefore be carried out with caution, and attention should be paid to possible deficiencies in such elements as manganese or copper. Local organic manures cannot cure a deficiency already present in local soils, since they themselves will also be deficient. However, the use of organic manures may act as an insurance against minor-element deficiency developing. If a deficiency is present, it may be aggravated by heavy manuring with inorganic fertilizers, because the larger crops produced will remove more of the deficient element from the soil. However, this difficulty is easily overcome by including a small amount of the deficient element in the fertilizers used.

In the eastern U.S.A., for example, there are considerable areas in which soils have been raised to a high level of productivity and apparent fertility, by the use of very heavy dressings of inorganic fertilizer (1 ton per acre or more, of fertilizer mixture, is used with crops like tobacco and potatoes). These soils are often sandy loams, which offer the best physical condition for cultivation in all weathers; and in recent years they have suffered severely from magnesium and other deficiencies. Non-acid-forming fertilizer mixtures containing dolomite are now used, and owing to their magnesium content, they are all the more effective in maintaining fertility [51].

Rice and plantation cultures are found in humid areas, but they occur more commonly in the following section (4), where they will be discussed.

Erosion control and soil conservation are important for soil-fertility maintenance, in this as in the other types of climate. Possibly the problem is less severe in this type, since the greater humidity makes it easier to secure the growth of vegetation that will prevent erosion or control gullies. However, there are many places in moderate-rainfall areas where erosion is serious, and where some soils have actually gone out of cultivation as a result of erosion. This is especially so where soils are naturally poor, where seasonal rainfall gives a pronounced dry season, and on steeply sloping land, such as the high hills and mountains that are commonly found in humid regions. The methods of soil conservation adopted resemble those already listed: land-use zoning, strip-cropping, contour cultivation, &c. Fertilizers are important for soil conservation to enable vegetation to cover eroded subsoils. Improved crop rotations and the use of animal or other organic manures are also helpful by giving the soil a better structure. Wind erosion or dust-blowing, of course, is rarely a trouble in this type of climate, although locally, in a dry season, some blowing of sandy soils may be observed.

4. *Heavy rainfall (perhumid) areas.*—The distinction between (*a*) temperate, and (*b*) tropical climates is particularly important here.

(*a*) In temperate climates grassland and forest tend to predominate over arable farming where the rainfall is high, cultivation being limited to that needed to produce fodder or to amplify the local food supplies.

(*b*) In tropical and sub-tropical climates, on the other hand, cultivation is widespread under heavy rainfall conditions, wherever a dense population has grown up. Elsewhere, in unsettled regions, forest or tall grasses predominate. One reason for the distinction is the growing of paddy rice in the tropics and sub-tropics, since this crop prefers moist or waterlogged soil conditions, whereas the crops of temperate climates suffer if the soil is too continuously wet.

Consequently, drainage is more important than irrigation in temperate perhumid climates; but irrigation, for paddy rice, may still be necessary in tropical and subtropical areas. Paddy rice needs much water at planting time, which may occur before the monsoon rains fall; in the event of a season slightly drier than usual, the heavy water-requirement of growing rice also makes irrigation beneficial. Thus we have the curious circumstance in China, for example, that 62 per cent. of the cultivated land is irrigated in the high-rainfall rice region, and only 18 per cent. is irrigated in the low-rainfall wheat region [52].

In perhumid areas even more than in humid ones there is a tendency for soil fertility to be limited by nutrient deficiencies, owing to the intense leaching; and in these even more than in those, animals (and probably humans) living on the produce of the local soils are liable to suffer from poor growth or actual diseases resulting from deficiencies of essential minerals from their diet.

Podzolized or lateritic soils (including red earths) are the rule in perhumid areas; nitrogen deficiency is almost universal; phosphate deficiency is frequent, often intensified by the high phosphate-fixing power

of red earths and laterites; lime deficiency is universal, though with some tropical crops liming may not be necessary. Curiously, a deficiency of potash is not so commonly or so acutely experienced as is deficiency of the other nutrients, although potash is usually needed on sandy parent materials, and some crops have special potash requirements. Minor-element deficiencies are also frequent, and many of these have doubtless still to be recognized in tropical areas where experimental work has been limited. Consequently, the soils of perhumid areas require heavy and regular manuring for high yields, and they give large fertilizer responses. Liming is not always a simple problem; for one thing, tropical and plantation crops, notably tea, often grow better in acid soils (these being their natural habitat), and for another, liming may accentuate a minor element deficiency. Lime, where needed, should therefore be applied with care, in moderation, and with attention to the possible existence of other nutrient deficiencies both major and minor.

Organic matter tends to be very low in cultivated tropical soils, under perhumid as well as other moisture conditions; and owing to the rapid breakdown and oxidation of added organic materials, it is very difficult to improve the soil in this respect. It should, however, be pointed out that the lateritic clays of tropical perhumid areas are friable and granular, not plastic and cloddy like the clays of other climates. The soil structure is consequently fairly good even though the organic-matter content is low; and it may not be so important to increase this constituent in the soils of the perhumid tropics as in other soils that have been discussed. The whole question of the relative importance of organic matter and the need for organic manures in tropical soils needs much further investigation: meanwhile, it seems best to take reasonable steps to incorporate organic materials, but not to go to uneconomic extremes.

In temperate perhumid areas, as in humid ones, grassland may be improved to a dramatic degree by the use of lime, phosphates, nitrogen when needed, and selected herbage species, along with good live-stock management. Under such conditions soils that were originally of very low natural fertility have been improved until their fertility is of the highest rank [1]. Heavy applications of deficient nutrients are required, and may continue to be necessary in order to counteract the effects of leaching, removal by live stock, and fixation; but the results make this well worth while. Under pasture erosion is not usually a problem, except where the topography is so steep that clearing of the bush and grassing-down have been followed by a serious development of landslides [53].

In tropical perhumid areas there should be great possibilities of grassland development in view of the rapid rate of plant-growth in the tropics, but there are also many difficulties [48]. In addition to the usual problems of herbage selection, manuring, and management, it is found that the lack of suitable legumes, the low mineral-content of the herbage, and the prevalence of live-stock diseases offer obstacles to grassland development. Much more research into both herbage and live-stock problems is needed. The diets of tropical peoples are often so deficient in protective foods of animal origin that the need is urgent from the point of view of human welfare also.

There are great areas of coarse grassland, maintained as such by annual burning, in the humid tropics which offer scope for development. They differ from the savannah grasslands of the semi-arid tropics in having a rainfall sufficient to give vigorous growth during much of the year, although the growth may be checked during the dry season. Examples are the *Imperata* grasslands of the world [54]; in south China alone these grasslands cover something over 100 million acres—an immense area of potentially useful land now waste. Frequently these grasslands occupy hilly or rolling country, not suitable for cultivation; but they could support live stock whose meat and milk products would supplement human dietaries. Methods of herbage improvement and of intensive grazing on such lands still have to be worked out; manuring will usually be necessary and probably extra mineral supplements for animals; these tropical grasslands form a valuable reserve for the future.

Where cultivation occurs in tropical perhumid areas, it is usually either (1) shifting cultivation by primitive tribes or peasant farmers; (2) traditional agriculture based on paddy rice; or (3) plantation culture. With regard to the first, the lines of improvement should, where possible, follow those of mixed or ley farming: this will improve both the fertility of the soil and the diet of the people. Various proposals have been made for incorporating mixed-farming methods in the agriculture of primitive peoples [1]; what is needed now is the application of the suggestions.

Where paddy rice is the chief crop, the special soil conditions tend to make the cultivation of other crops difficult, and on alluvial plains given to rice-growing there is little room for grazing animals. However, if the winter is too cold for rice, other crops can be grown, provided care is given to their cultivation (as in central China): this makes a rotation of crops possible. Some live stock are always kept, as work animals, fed on rice straw supplemented by weeds or specially-grown fodder crops; there are often some pigs or goats. Where paddy fields are cultivated in hilly country, live stock can readily be grazed on the hillsides. Thus mixed farming of a special type is possible even in conjunction with the culture of paddy rice. Soil organic matter may also be maintained by ploughing-under rice straw along with inorganic nitrogen.

The peculiar soil conditions imposed by rice, and their relation to soil-fertility maintenance, have been discussed [1]. Moisture supply not normally being a limiting factor, paddy rice tends to give a higher yield of food per acre than other cereal crops. Because paddy soils are usually leached in nature, large responses to fertilizers and manures are generally secured. For example, in China the writer estimates that the average yield of paddy rice can be increased by 30 per cent. by a moderate use of inorganic fertilizers, in addition to the local manures already employed. In India, where rice has been little manured in the past, even larger average increases from fertilizers are probable [55].

Nitrogen increases rice yields almost everywhere, ammonia generally being more effective than nitrate; phosphate sometimes appears ineffective, especially on rich alluvial soils, where, however, it might become necessary if nitrogen were used alone for any considerable period. If bulky

local organic manures are employed, they may prevent such a deficiency developing [56]. On some phosphate-deficient tropical soils, on the other hand, the limiting effect of the deficiency is so severe that rice may give little or no response to nitrogen unless phosphate is also present; with the combined application of N and P there is a large positive NP interaction. Potash is not always effective with rice when local organic manures or ashes are used; but where the local custom is not to manure rice, then potash may be necessary as well as nitrogen and phosphate. There is some evidence that bulky organic manures as well as inorganic fertilizers are necessary in order to get the best results, if rice is grown continuously, without other crops or fallows.

To improve and extend the cultivation of paddy rice is an important method of increasing food production in regions where rice culture is practicable. Even in hilly country rice-growing can be extended by the use of terracing, and this (the construction of level bench-terraces) is at the same time an excellent method of soil conservation. Thus, provided the crop is adequately manured, the cultivation of paddy rice is a method of improving soil fertility as well as increasing the food supply. Dryland or upland rice is also grown in some areas, but it is not a crop to be encouraged: it gives much poorer yields than paddy rice, and if grown on sloping land it leads to accelerated soil erosion.

Apart from paddy rice, most of the crops cultivated in the tropics are liable to set up severe erosion, because tropical downpours are so intense (there may be 10 in. or more in 24 hours) that even the most gently sloping land suffers from sheet and gully washing. This helps to explain why, under shifting cultivation, it is necessary for the cultivators to move on in so few years after breaking fresh soil; it also emphasizes the need of careful erosion control as a long-term policy throughout the tropics, under both native and plantation agriculture. It may take a long time to induce native cultivators to see the need for this, but it has forced itself on the notice of plantation managers in no uncertain fashion, and between the two wars there has been almost a revolution in plantation practice in consequence [1].

In plantation agriculture, managers formerly aimed—as in temperate climates—at clean cultivation and the suppression of weeds: now some kind of cover-cropping or selective weeding is very widely practised, except where the land is flat. It is important for soil-fertility maintenance that these and other soil-conservation practices, such as contour ridging or strip-cropping for sugar-cane and cotton, should be adopted on all sloping land under plantation agriculture.

Owing to the varying requirements of different soils and crops, and the complications introduced by shade trees and cover-cropping, the manuring of plantation crops is a complicated subject, which can hardly be summarized in a few sentences [57]. It does appear, however, that whereas nitrogen alone is sufficient for tea on most soils [58, 59], other plantation crops (including sugar-cane, cotton, coffee, rubber, cacao, and coconuts) require more complete manuring, although the response may sometimes be slow in appearing or difficult at first to measure. Sugar-cane in particular can make good use of very large fertilizer applications

[60]. There is a good deal of evidence for the value of animal or other organic manures; to propose that they should be employed generally in plantation practice may be a counsel of perfection, yet composting or the turning-under of crop residues or green vegetation can be practised, whilst some plantations keep a herd of cattle for no other purpose than to make manure for the trees. Such manure may be applied on a ring of clean-cultivated soil around the trunk of each tree, the intervening ground being protected against erosion by the cover-crop or selected weed-cover.

As a result of these recent developments it can be said that whereas ten years or so ago plantation agriculture often appeared self-destructive through the erosion and impoverishment of the soil that ensued, we may now hope that well-managed plantations will not only preserve but improve soil fertility—whilst badly managed plantations will in time go completely out of production. Indeed, well-managed plantations of tree or bush crops, in which the soil is protected by cover-crops or by selective weeding, may offer the best practical alternative to afforestation, in protecting tropical hillsides against erosion.

Reviewing the perhumid areas as a whole, we can say that there is considerable room for grassland improvement, with the use of lime and fertilizers; and that when well carried out, this will greatly increase soil fertility. With the cultivated crops, whether those of peasant cultivators, paddy rice, or plantation crops, there is a marked need for both organic manures and inorganic fertilizers. Although the best methods of maintaining the soil organic matter under tropical conditions still have to be worked out, the broad principles of modern intensive agriculture can be applied. This will require, in addition to manures and fertilizers, the use of crop rotations or leguminous cover-crops, and the keeping of live stock to provide the organic manures. It seems at present that in the humid tropics and sub-tropics, mixed farming methods will be easier to employ than alternate husbandry.

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SOME ASPECTS OF SOIL FERTILITY IN CYPRUS

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THE principal occupation of the people of Cyprus is agriculture, and the chief crops, apart from those grown under permanent irrigation, are cereals in the lowlands and grapes in the hills. The main cereal-growing area is the central plain, the Mesaoria, which, bounded by high hills to the north and to the south, rises from the coasts on the east and west sides of the island to a height of about 600 ft. in the neighbourhood of the capital, Nicosia. The climate in this belt is of the extreme Mediterranean type with a long, hot, and practically rainless summer, followed by a cool winter season when the rains fall. The annual rainfall in different parts of the Mesaoria varies from less than 12 to 15 in., averaging about 13½ in. Of this rain, 90 per cent. falls in the six winter months, November to April, and although local thunderstorms may occur in any of the summer months, from an agricultural point of view the four months June–September may be considered as rainless. There is great variation from year to year, both in the amount and—of equal importance to the farmer—in the distribution of the rain. There are no perennial streams in the Mesaoria, but the river-courses carry flash floods following any period of heavy or prolonged rain, and it is a characteristic feature of the cereal-growing areas that, wherever possible, this water is led off from the river-beds by low weirs and, conducted through a maze of channels, used to supplement the ordinary rainfall by flood irrigation of the growing cereals. Late spring floods (March–April) are of especial benefit to the wheat crop, and should the spring rains fail, the crop is usually very poor.

The basic rotation followed is cereal–bare fallow, i.e. the land is cropped only once every two years. Barley is sown in the poorer and wheat (durum types) in the richer fields in autumn and reaped in May and June. The stubble is grazed over by sheep until the following spring, when it is ploughed once or twice in preparation for a cereal crop the following autumn. Various legumes, especially *Vicia ervilia*, may be sown in the better fields in the fallow year, but such legumes occupy only about one-quarter of the total fallow. The average yield of wheat is about 12 bu. per acre. This includes yields from a considerable area of marginal land, and in good soils, in favourable years, yields of 30 or even 40 bu. are said to be obtained.

The object of this paper is to discuss the results of a number of experiments which throw some light on the general question of soil fertility in the cereal-growing areas of Cyprus.

Experimental

In 1933 three experiments were laid down at the Central Experimental Farm of the Department of Agriculture situated at Morphou in the

western Mesaoria. In two of these trials wheat has been grown continuously under various manurial treatments, and in the third various simple two-course rotations are compared. Each of the three trials is laid out as a 4 × 4 Latin square. The rotation trial was not, unfortunately, replicated for years. The treatments are as follows:

Trial A. Type of manure trial: wheat grown every year.

Treatment I. No manure or artificials.

Treatment II. Nitrogen only: 68 lb. per acre of sulphate of ammonia broadcast at sowing plus 68 lb. per acre of nitrate of soda given as a top-dressing in spring.

Treatment III. Phosphate only; 340 lb. per acre of superphosphate broadcast at sowing.

Treatment IV. Sheep manure; 9 tons per acre ploughed in before sowing.

Trial B. Amounts-of-fertilizer trial: wheat grown continuously.

Treatment I. No manure or artificials.

Treatment II. Small dressing of artificials; 170 lb. superphosphate and 34 lb. sulphate of ammonia broadcast at sowing, plus 34 lb. nitrate of soda as a top-dressing in spring.

Treatment III. Medium dressing of artificials. Twice the quantities used in Treatment II.

Treatment IV. Heavy dressing of artificials. Twice the quantities given in Treatment III.

Trial C. Rotation trial: wheat grown every other year (except in Treatment I). No manure or artificials given.

Treatment I. Wheat grown continuously.

Treatment II. Wheat followed by a bare fallow.

Treatment III. Wheat followed by *Vicia sativa* ploughed in as green manure.

Treatment IV. Wheat followed by *Vicia sativa* taken for seed; stubble ploughed in.

These three trials were laid down side by side in the same field, which had previously been fallowed for 18 months.

The soil is alluvial, of poor basic fertility, and the rainfall on the site of the trial is below the average for the cereal-growing areas. Facilities exist for flood-irrigating the trials with river-water as is customary in the country, but in years where this has failed it has been usual to irrigate once with pumped water. The breakdown of the pumping installation in 1936 in a critical season resulted in almost complete crop failure. The necessity for flooding results in an additional variable being added to the factors which make for soil heterogeneity, since it is very difficult to ensure that all plots receive the same amounts of water. Probably because of this, but also because the plots are large—$\frac{1}{12}$ acre—the standard error in the experiments has always been higher than one normally expects to find in cereal experiments. Although it is not strictly permissible to compare treatments from the different trials,

the three trials are contiguous with each other and all contain one common treatment (wheat grown continuously without manure). It is proposed to consider the results of these trials together, along with certain other short-term experiments and miscellaneous data.

Results

The results of the three permanent trials described above are shown in Tables 1, 2, and 3 for the years 1934–44 inclusive. It will be observed that there are very considerable variations from year to year, which obscure the major trends that have occurred over the period. Fig. 1 is constructed by taking a 3-year moving average over the whole period of the experiments, which tends to smooth out the annual variations and gives a picture of the general trends of the yields under the different treatments. The significant differences are not shown in Table 2, as the responses to the various doses of artificials are so apparent and so consistent. The mean annual yields shown in this table indicate the range of variation which is experienced from year to year.

TABLE 1. *Type of Fertilizer Trial: Yield of Wheat Grain (lb. per Acre)*

Harvest year	*Treatment I no manure*	*Treatment II N only*	*Treatment III P only*	*Treatment IV sheep manure*	*Sig. diff. $p = 0{\cdot}05$*
1934	640	670	880	780	109
1935	640	990	595	1,020	126
1936	60	100	65	90	24·7
1937	435	700	530	1,420	545
1938	245	255	320	890	210
1939	160	175	165	885	288
1940	50	65	85	715	252
1941	65	75	135	700	243
1942	480	590	465	1,090	155
1943	120	80	160	845	317
1944	220	215	355	605	245
Mean	283	356	341	822	—

TABLE 2. *Amount of Fertilizer Trial: Yield of Wheat Grain (lb. per Acre)*

Harvest year	*Treatment I no manure*	*Treatment II small dressing*	*Treatment III medium dressing*	*Treatment IV large dressing*	*Mean*
1934	745	1,005	1,080	1,195	1,006
1935	540	710	780	1,085	779
1936	60	60	85	65	68
1937	490	1,075	1,160	1,635	1,090
1938	280	545	840	955	655
1939	145	430	545	955	519
1940	80	220	400	720	355
1941	190	405	490	830	479
1942	360	560	810	1,265	749
1943	195	395	550	860	500
1944	295	530	650	955	608
Mean	307	540	672	956	—

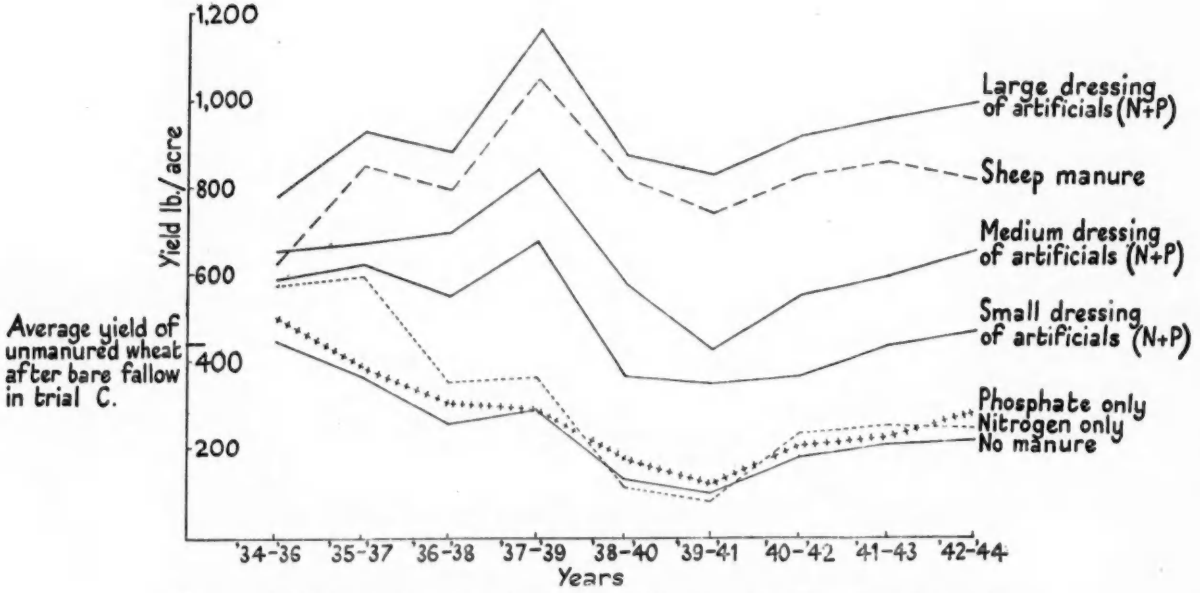

FIG. 1, showing trend of yields of wheat under various treatments of continuous manuring

TABLE 3. *Rotation Trial: Yield of Wheat Grain (lb. per Acre)*

Harvest year	*Wheat–wheat*	*Wheat–Bare fallow*	*Wheat–Green manure*	*Wheat–legume*	*Sig. diff. $p = 0.05$*
1936	75	155	280	120	87
1938	255	865	1,080	560	549
1940	65	100	215	115	107
1942	280	730	1,310	655	284
1944	190	335	410	270	159
Mean	173	437	659	324	242

Discussion

It is popularly supposed in Cyprus—and in other semi-arid countries where fallowing is a regular feature of the cropping system—that a bare fallow is necessary in order to conserve two seasons' rainfall for the growing of one crop. This has been shown to be completely fallacious, since yields well above average can be maintained for at least 10 years by adequate manuring with nitrogen and phosphate, either in the form of artificial fertilizer or organic manure. The usual practice in Cyprus is to manure wheat—if manure is given at all—with superphosphate alone or with a compound such as 4–12–0 containing very little nitrogen. In this respect Cyprus practice differs markedly from English, but it must be remembered that in Cyprus wheat usually follows a bare fallow. The yields in Trial A explain the probable reason for the Cyprus practice. In the first year of the experiment—following on a cultivated fallow—'phosphate only' gave a significant response as compared with 'no manuring,' whilst 'nitrogen only' gave no response whatsoever. In succeeding years phosphate has given no response whatsoever, whilst in the 2nd and 3rd year 'nitrogen only' gave a significant response. In the 4th the response to nitrogen only is high, but not significant, but from the 5th year onwards the 'nitrogen only' plots, like the 'phosphate only' plots, have given practically the same yields as the 'no manure' plots. The explanation seems to be that under ordinary conditions the amount of available nitrogen and phosphate in Cyprus soils is just sufficient to give a moderate crop. Preliminary investigations on the effect of fallowing on soil moisture and soil nitrogen [1] indicate that although there is no apparent effect on the moisture-content, the quantity of soluble nitrogen present in October (i.e. at the end of the dry season and just before sowing-time) is 5 to 6 times as great in land that has been fallowed in the previous winter and during the summer as in land that had borne a crop during the previous winter. It would seem that, after a fallow, the yield of wheat is limited by the amount of available phosphate. Hence, after a fallow, wheat responds to phosphatic dressings. When wheat is grown continuously no nitrogen accumulates and hence wheat will respond to added nitrogen, but only until the available phosphate in the soil is exhausted—apparently after about 4 years in the soil in which these experiments were carried out. Thereafter no response to nitrogen alone is obtained because lack of phosphate limits the yield.

No response is obtained to phosphate only after the 1st year, because lack of nitrogen limits the yield.

The difference in yields obtained from phosphate and nitrogen singly (Treatments II and III in Trial A) compare strikingly with the yields obtained from the same quantities of phosphate and nitrogen together (Treatment III, Trial B), and the trends of the yields are clearly brought out in Fig. 1 (p. 126). There is no doubt that the main benefit derived from a bare fallow is not the accumulation of water but the accumulation of available nitrogen and probably, to a lesser extent, of phosphate. Richardson and Gurney [2] have shown that very similar conditions obtain in South Australia and, in the semi-arid country of Northern Nigeria, Hartley [3] has demonstrated that nitrogen and potash are of no value when applied by themselves to a crop of guinea corn, but that phosphate is the all-important mineral.

The average analysis of sheep manure (which is the usual organic manure available in Cyprus) is (per cent.): H_2O, 20; N, 1·25; P_2O_5, 0·50; and K_2O, 1·25. The dressing of 9 tons sheep manure per acre applied in Treatment IV, Trial A, supplies 240 lb. of nitrogen, 98 lb. of phosphate (P_2O_5), and 240 lb. of potash (K_2O), or roughly 4 times as much nitrogen, and as much phosphate as does the heavy dressing of artificials (N plus P) in Treatment IV, Trial B. It is apparent, since the yield is no greater than that obtained from N plus P alone, that there must be ample reserves of potash in the soil, which is in line with the results obtained with manurial trials on potatoes in Cyprus, in which no response was obtained to potash; again a striking contrast to United Kingdom conditions. The mean responses to the three levels of manuring in Trial B are practically linear (Fig. 2, p. 129), and it is apparent that, under the conditions of the experiment, the upper limit of wheat yields has not been reached. At higher levels of nitrogen plus phosphate manuring either potash or water-supply might limit the yield. No data are available as yet as to the optimum dressings of phosphate or nitrogen, but the results of the manurial trials with potatoes mentioned above indicate that the amount of phosphate necessary to give the soil a satisfactory nutrient status for good crops is comparatively small, and that thereafter nitrogen gives large responses. It is probable therefore that the response to the heavy dressing of artificials is largely due to the nitrogen acting in a soil which has had more than sufficient phosphate added to it.

The comparison of the yields obtained from the large dressing of artificials (Treatment IV, Trial B), and from the dressing of sheep manure (Treatment IV, Trial A), is of considerable interest in view of current controversies regarding the respective merits of organic and inorganic manures. It is obvious that the results of these trials give no indication whatsoever that organic manure—as represented by sheep manure—has any effect on the yield of cereal, apart from the effect which might be expected from its contained nutrients. In this respect the results agree with those obtained in Trinidad by Wood and Hardy [4], and with Hartley's results [3] from Northern Nigeria. It is apparent, too, that the nitrogen in the sheep manure is probably much less

than half as effective as the nitrogen in the artificials, which is the proportion that Russell and Watson [5] find in the Broadbalk experiments at Rothamsted.

A further comparison of organic and inorganic manures was afforded by an experiment carried out in 1940–1, which was designed primarily

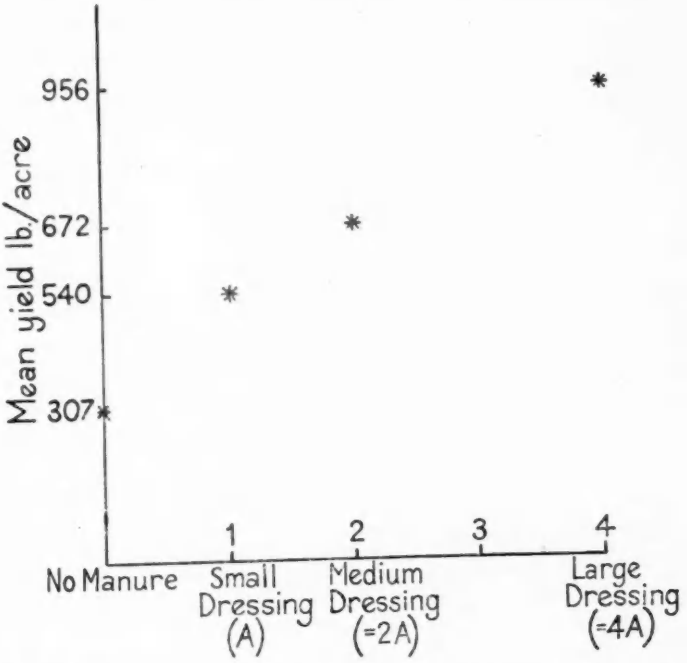

FIG. 2, showing mean response to three levels of manuring (Trial B).

to test the value of composted town refuse as a manure. The following treatments were compared in a Latin square:

A. Farm-yard compost, made by composting chopped straw and farm refuse with stable sweepings (this being the closest approach to FYM obtained in Cyprus): 12 tons per acre.
B. Composted town refuse: 22½ tons per acre.
C. Sheep manure: 3 tons per acre plus 3 cwt. per acre superphosphate.
D. 12 cwt. per acre of 6–8–8 compound fertilizer.

The quantities of organic manures were estimated to be about equivalent in NPK content to the artificials which were applied at the rate usually applied to potatoes in Cyprus at that time. Superphosphate was added to the sheep manure, as it was known to be comparatively deficient in phosphate. Samples taken at the time of application of the

manures showed that the actual NPK content varied considerably. The analyses were as follows (per cent.):

	Farm-yard compost	*Town refuse compost*	*Sheep manure*
H_2O . . .	43·68	19·04	20·4
N . . .	0·65	0·18	1·33
P_2O_5 . . .	0·26	0·21	0·65
K_2O . . .	0·53	0·20	1·47

and on this basis the various treatments would be equivalent to the following applications of minerals in lb. per acre:

Treatment	N	P_2O_5	K_2O
A	175	70	142
B	91	106	100
C	89	98	98
D	80	107	107

i.e. Treatments B, C, and D are roughly equivalent, but Treatment A supplies twice as much nitrogen and 1½ times as much potash, but rather less phosphate. The quantity of phosphate in Treatment A is, however, equivalent to a dressing of about 3½ cwt. of superphosphate per acre, which should be sufficient to ensure a satisfactory phosphate-status in the soil.

Potatoes were planted in August 1940 and harvested in November. The plots were immediately prepared for wheat, which was sown in December 1940 without any further manurial treatment and harvested in June 1941. The results were (lb. per acre):

Treatment	*Yield of potatoes*	*Yield of wheat*
A	5,700	1,230
B	5,660	1,410
C	6,100	1,390
D	6,420	2,150

The differences in the potato yields are not statistically significant, whilst the yield of wheat in Treatment D is very significantly higher than the yields from the other treatments, between which there is no significant difference.

The very high residual effect of the artificials is outstanding, and there is no sign that the organic manures have contributed anything of special value to the soil. In Uganda [6] it has been stated that 'farm-yard manure merely feeds the crop and has no effect in reforming the structure of the soil'. Under Cyprus conditions it is unlikely that leaching is of much importance in removing minerals from the soil, and there is no doubt that under the conditions of high summer temperatures organic matter breaks down very rapidly. Peat [7], in discussing the

maintenance of organic matter in tropical soils, states that, when the soil temperature rises above 77° F., accumulations of organic matter cannot take place. In Cyprus the mean daily maximum shade temperature exceeds 80° F. for six months in the year: the mean soil temperature must therefore be considerably higher than 77° F. for a considerable period in the year, and it would seem possible that, under such conditions, some of the nitrogen is lost in a gaseous form. Even between the various forms of organic manures, the very bulky town refuse shows no advantage as compared with the very much more concentrated sheep manure. Estimates of organic matter have been made of the soils from the plots under the various treatments described in the long-term experiments above. The analyses were carried out by the method of Walkley and Black in January 1940, when all plots carried wheat. The results were:

Treatment of plots	*Organic matter %*
No manure	0·30
Nitrogen only	0·59
Phosphate only	0·81
Sheep manure	1·66
Light dressing of N plus P	1·00
Medium dressing of N plus P	0·98
Large dressing of N plus P	1·01
After bare fallow	1·00
After vetches for seed	0·98
After vetches ploughed in	1·24

Comparing these figures with the yields shown in Tables 1–3, there is no evidence of any direct correlation between organic-matter content and yield. The green-manure plots showed a relatively high organic-matter content, as compared with soils under any of the other rotations, but the increase is small in absolute units, and seems hardly sufficient to account for the high yields obtained after a green-manure crop. The actual amount of organic matter in the green-manure crop is very small, for the vetches rarely grow more than 9–12 in. high before they are turned in. It is probable that much of the value of the green manure is in the additional nutrients which it makes available for the succeeding crop. It has been demonstrated in Nigeria [8] that on certain soils the whole value of an organic manure can be explained in terms of its phosphate-content. Since Cyprus soils are apparently deficient in available phosphate, the green manure will obviously exercise a profound effect on the succeeding crop merely through the making available of additional phosphate. Given that sufficient additional phosphate is made available, the extra nitrogen furnished by the legume would also have an effect. That this is a likely explanation is shown by the reduction in the yield of wheat after a harvested legume (the legume stubble remaining to be ploughed in) as compared with the yield after a bare fallow (Trial C). Although in no year does the difference reach statistical significance, it has been so constant as to be almost certainly a real effect, and is indeed recognized as such by the ordinary Cypriot farmer. It is apparent from the various results quoted above that the importance of

organic matter in the soils of a semi-arid region can be greatly overestimated. Organic matter *per se* is of no importance in arable agriculture in Cyprus from the point of view of maintaining crop yields. It is useless to talk of building up the organic-matter content of the soil since as fast as organic matter is put in, so it burns out, and whilst in no way decrying the merits of organic manures, *if easily and cheaply available*, it is clearly impossible to build up the organic-matter content of Cyprus soils to a level with that obtaining in western European soils, except by very heavy and continual applications of organic manures, which under the agricultural and climatic conditions obtaining in Cyprus are not, and cannot be, available.

Moreover, it would appear that, provided good crops are grown, the organic-matter content of the soil will look after itself and become stabilized at a suitable figure (at Morphou about 1 per cent.). As Milne [9] says: ' If the soil is to continue to grow plants for us, in turn we must grow plants for the soil.' Recent experiments in Uganda [6] have shown that a resting period under elephant grass will restore the fertility to worked-out soils; and in Trinidad [10] it has been found that the fertility of sugar-cane fields can be perfectly well maintained on artificial manuring and that pen manures are not essential; it is in fact the growing plant which maintains, and may increase, the organic matter and fertility of the soil, just as much as does the soil maintain the growing plant. Provided an adequate nutrient status is maintained in the soil, where necessary by the addition of either organic or inorganic manures, and as long as growing plants are maintained on the soil, so will the fertility remain. A recent description [11] of the reclamation of pit-mounds in Worcestershire brings out the same facts, for, in spite of the incorporation of large quantities of organic matter in various forms (sugar-beet waste, sewage waste, green crops, &c.), it was not until the ground had received an adequate dressing of artificials that a short ley could be sown, which proved highly successful. Previous attempts to grow either a ley or other crops without artificials had been failures.

The economics of growing continuous wheat, and wheat under the various rotations and treatments described, were examined by James and Koumides [12], who concluded that, at the price-levels of grain and fertilizer before the war, the most economic form of rotation or treatment (for a highly capitalized farm) was wheat followed by a harvested legume. Though it is possible that further experiments (which it is hoped to initiate shortly) may show that it will be possible to obtain yields as high as those obtained with the high dressings of artificials in the experiments described, by using cheaper mixtures (e.g. with less phosphate), it is certain that at the price to which nitrogenous fertilizers have now risen it is even less profitable to attempt to grow continuous wheat.

The use of green manure, which, on paper, appears promising, is in practice attended by several difficulties. To be effective the green manure must be sown early and turned in before the end of the rainy season. If it is turned in too early, it has made so little growth that it is barely worth growing; if left too late, the soil dries up and the haulms dry up with it and do not decompose till the following season. To sow early

means that the green manure competes for time and labour with the cereal crops, and under the non-mechanized condition of Cyprus farming this invariably must mean that it would always be sown too late. The greatest difficulty of all, from the peasants' point of view, is the turning in, for the ordinary implement used for cultivation is the 'nail' plough, and even where iron ploughs are used, they are of the short 'digger' type. Neither implement can deal satisfactorily with a green-manure crop, which requires to be well turned in and buried. Although statistically there is no evidence of deterioration in yield of the plots receiving nitrogen plus phosphate, the permanent manurial plots have become more and more infested with weeds—principally wild oats—until in 1944–5 it was necessary to fallow half of each plot in order to try to control the weeds. The wild oats grew particularly rankly on the sheep-manure plots, and to a rather less extent on the plots receiving the heavy dressing of artificials. In the 'no manure' plots the wild oats, though present, made very little growth and probably did not depress the yield to any significant extent. There is little doubt that apart from economic factors any scheme for continuous wheat-growing would soon break down owing to infestation with weeds.

Summary.—The climatic conditions obtaining in the cereal-growing areas of Cyprus are described, and the results given of three experiments that have been in progress since 1933, which throw some light on the problems of soil fertility in Cyprus. From the results of these and other experiments and data, it is argued that:

(1) The arable soils of Cyprus have a very poor reserve of available phosphate and nitrogen.
(2) The chief value of a fallow is the formation of an adequate amount of available nitrogen for the succeeding crop.
(3) There are ample reserves of potash in the soil.
(4) There is no evidence that organic manures have any value other than their contained nutrients, and the efficiency of these nutrients is very low as compared with equivalent nutrients in artificials.
(5) Adequately grown crops will maintain a satisfactory organic-matter content in the soil irrespective of how the soil is manured.
(6) Infestation with weeds is the only reason (other than economic ones) why wheat, provided it is adequately manured, cannot be grown continuously in Cyprus.

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THE OYO FARM SCHOOL, NIGERIA

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Need of rural rehabilitation.—Progress in Nigeria during the past 30 years has been very considerable, yet in the most important industry of the country, agriculture, methods have changed but little and farming continues to be largely traditional. In the southern provinces of Nigeria, where education has been much more widespread and of longer duration than in the northern provinces, its influence on the development of the country has been remarkable, but the system of teaching generally adopted in schools is largely urban and comparatively unrelated to the needs of the country-side. In consequence of this, boys on leaving school look for some form of salaried employment; they maintain, quite justifiably, that farming by the traditional methods involves hard work for poor remuneration. Village life has no appeal, and sooner or later educated youths find their way to the town in the hope that some form of urban employment will come their way.

This drift of educated boys away from the country-side must sooner or later constitute a serious social and economic problem to the country. Nevertheless, until farming can be proved to be a more remunerative occupation than it has been in the past there can be little hope of any rural rehabilitation by the educated section of the community.

The Agricultural Department has for many years been investigating the economics of Native agriculture. It is now thought that farming can offer a livelihood at least equal to, if not better than, many types of employment, particularly for schoolboys with only an elementary education. This, however, involves some form of vocational training. Boys need first to be taught better methods of farming and led to appreciate the many amenities which rural life can offer.

The Oyo Farm School is an experiment in vocational training which seeks a solution of these problems. Its immediate objectives are to determine suitable methods of training and settling elementary schoolboys on the land, and the amount of capital required to enable them to make a reasonable livelihood from farming. The school was opened in January 1942, and up to the present only one class of students has actually passed through the school and settled on the land.

Recruitment of the first class of students.—This recruitment was carried out by notifying all administrative and educational authorities in the district of the opening of the Farm School, and inviting them to submit the names of any suitable candidates. No examination was held, the selection of students was made by personal interview by the officer in charge. A short list of 20 applicants was chosen for trial with the object of admitting the 12 best candidates as judged by their general interest and aptitude for farm work. The final selection consisted of boys from a wide variety of occupations and of various ages ranging from 17 to 27 years. Three of them were married, and with one exception all of the

students had left school for several years and been engaged in occupations other than farming.

Settlement of the first class of students.—Although the Farm School was not intended to be a land-settlement scheme, it was considered desirable in certain circumstances that provision should be made for a limited number of students to be allowed to settle on the Farm School Estate. The primary object of this concession was to ensure that any student passing through the school should not be denied the opportunity of engaging in farming through lack of suitable land.

Of the first class of 12 students, 7 applied to settle at the Farm School. This was admittedly a somewhat high proportion of the total class; nevertheless, after taking all the facts into consideration, it was decided to admit this number. An important fact which influenced this decision was the demonstration value which, it was hoped, these settlers would provide for successive classes. It was made clear to the students concerned that a very high standard of farming would be expected of them. Furthermore, from the point of view of determining future policy, this group should provide much valuable information particularly as regards the best methods of setting up subsequent students in farming and the expenditure that is involved. All 7 of the Farm School settlers have engaged in a system of farming which includes the keeping of cattle, sheep, goats, and poultry, and all have elected to cultivate their farms by hand rather than with a plough.

Each student has been allocated 4 acres of good land for the cultivation of annual crops. Buildings for their live stock have been provided, and there is abundant grassland available for their cattle. A sum of £10 was granted to each settler to build a house for himself, and the settlers have erected a small village near to their stock-pens and cultivated land. The settlement of the students in a group was for many reasons the only practical method that could be adopted. In practice the system appears to be very sound indeed, as a virile community life is noticeably developing.

Of the 5 students who have gone back to their own villages, 2 elected to go into partnership on a mixed farm cultivated by plough. These 2 students are, incidentally, the only ones who expressed a wish to take up this method of mixed farming. The third student has a mixed farm with cattle and poultry. The fourth has taken up pig-keeping and the fifth decided to keep only poultry.

There is therefore a very wide variation in the methods that are being practised by the first class. It is an entirely spontaneous development arising from each student's own conception of the type of farming most suited to his circumstances and inclinations. They should provide a most valuable field for observation and inquiry in many important aspects of mixed farming, embodying also both the individual and group method of settlement.

Recruitment of the second class of students in 1943.—As one of the primary objects of the Farm School is to attract educated boys back to the land and provide them with a sound vocational training in farming, the recruitment of the second class of students was restricted to elemen-

tary schoolboys who had not left school for more than one year. In practice most of the boys came straight from their elementary schools. To attract the best boys, a scholarship scheme was instituted whereby selected students were awarded a scholarship of a maximum value of £60. This amount is intended to cover subsistence during the course of training and also to provide the student with the necessary capital for buildings, live stock, and equipment, on the completion of his course. No guarantee is implied that the full amount will be awarded. The actual amount granted depends, firstly, on the aptitude and ability for farm work displayed by the student during his course of training and, secondly, on the actual amount necessary to set him up in the type of farming which he ultimately chooses to follow. The scheme was restricted at first to those schools in Oyo Division which had school farms and agricultural teachers trained at Ibadan under the Agricultural Education Scheme. The selection of students for scholarships is based on a simple examination and personal interview.

The curriculum.—The first year (1942) of the Farm School was very much a period of opening up training farms and exploring the best methods of approach to the problem of instruction. By the middle of the year a settled policy was evolved and put into operation, and it appears to be developing satisfactorily. The most important change which became operative with the second class of students was the extension of the length of the course of training from 1 to 2 years.

During the first year the students are given as comprehensive a training as possible in all branches of mixed farming. It should be emphasized, however, that the methods taught are applicable only to the savannah woodland conditions that obtain in the Middle Belt territory of Nigeria. Three training farms have been opened up for this purpose whose objects are as follows:

Farm 1. A mixed farm of 4 acres with annual crops on which the use of cattle-drawn implements is demonstrated. These include a plough-cultivator and farm-cart. The live stock consists of two work-bulls and three cows. All the cattle are the local type of Zebu × Brachyceros commonly seen throughout the district. The object of this farm is to teach the value of animal draught combined with good cattle husbandry.

Farm 2. A farm of 4 acres of annual crops on which only hand-cultivation is adopted, employing the standard type of hoe used throughout the western provinces. The stock consists of 4 cows and one bull, all of which are shorthorns. The object here is to teach rotational cropping, using local methods of cultivation combined with cattle husbandry.

Farm 3. A farm of 2 acres of annual crops on which hand-cultivation similar to that on Farm 2 is adopted. The stock consists of sheep, goats, pigs, and poultry. The object is to teach improved methods of small live-stock management combined with a system of rotational cropping. All the manure produced is composted before use on the land.

On all three farms areas of natural pasture adequate for the stock superior requirements have been incorporated. In some instances

types of grass have been planted for grazing, stall-feeding, and hay-making. Special emphasis is also laid on the maintenance of soil fertility by the use of farmyard manure and green manures and the protection of the soil from erosion by contour-ridging.

Whilst each training farm is intended to be a complete unit demonstrating different methods of mixed farming, it is not intended that any of them should necessarily be followed exactly. Their purpose is to enable the student to study as wide a variety of methods as possible, and to assist him to work out for himself a system of farming most suited to the circumstances under which he will farm when he finally leaves the school to take up farming on his own. For example, a student may elect to keep cattle, sheep, and poultry, and adopt hand-cultivation on his arable land. He therefore combines the relevant features of Farms 2 and 3 with such modifications in the cropping as may be considered necessary to suit the local conditions of the district in which he will ultimately be farming.

During the second year of the course each student is given 1½ acres of land to farm on his own. He is encouraged to exercise his initiative to the fullest extent and to put into operation the substance of his first year's training on the training farms. Arrangements are also made for him to keep some stock. All crops raised on these farms are the property of the students, and any stock which is provided is taken away by them when they leave the school on the completion of the course. The cost of any equipment and stock provided during the second year of training is debited to the student's scholarship account.

The primary objects of the second year's work are, firstly, to give the student a year of farming on his own under close supervision and, secondly, to ascertain his aptitude and ability for farming. The degree of progress achieved during the second year also affords a useful basis for determining the actual amount of the scholarship grant which will be accredited to each student when he returns to his village.

Classroom work.—As the course of instruction is essentially practical, classroom work is reduced to a minimum. Provision is made in the time-table for one hour's classroom work a day, but during the busy season, such as planting-time, the period is reduced if the farm work is likely to suffer. All academic subjects are avoided, and during the first year teaching is confined to keeping a farm diary and recording the objects and advantages of the various methods employed on the training farms. The students weigh all crops and calculate yields per acre, live-weight gains of stock, &c. All teaching is carried out in English, and it is remarkable how quickly the students' knowledge of the language improves, as well as that of arithmetic, without their realizing that they are being taught either subject. Thus by the time they begin the second year of their training a fairly uniform standard of progress in both these important subjects has been attained by the whole class and they are ready to absorb more advanced work. Second-year classroom work includes lessons in livestock husbandry, farm management, veterinary work, village hygiene, and simple farm accounting. The lessons take the form of a general discussion, and students are encouraged to express

their own views freely. Facilities are available for instruction in carpentry and smithery during the second year for any students who wish to take up this work.

Recreation.—The usual ball games such as football and basket-ball that are played in elementary schools would normally be continued during the Farm School course, but at present the necessary equipment is unobtainable. As many other recreational facilities as possible have been provided, namely, teniquoits, table tennis, chequers, draughts, &c. In addition, students are encouraged to think out their own forms of entertainment and to join in local social activities, such as hunts and festivals.

Liaison with local farming community.—When the Farm School was first started the local farming community viewed it with some suspicion. This attitude rapidly broke down largely on account of the tact and friendliness exercised by the African Instructor. It was not long before the curiosity of the neighbouring farmers was aroused and farmers began to come to the school voluntarily to see what was being done. Periodically they organize themselves into parties from villages as far distant as 10 miles in order to see the crops on the training farms and to inspect the live stock. Although none keep cattle themselves (all cattle husbandry in the district being undertaken by Fulani settlers from the northern provinces), the Farm School stock are always a source of great interest, and it is often difficult to convince them that the bulls trained at the school for draught purposes, such as ploughing and carting, were purchased in the locality and not imported.

This liaison with the local farming community is a very encouraging feature, and in order to foster its development classes of students are taken occasionally to selected neighbouring farms where local farm practices and problems are discussed.

Post-school settlement.—A 'mixed-farmer' requires land for grazing his cattle as well as for annual crops. At least 10 acres per student will generally be necessary for this purpose. It is important that the land should be reasonably fertile and that the site of the farm should be fairly near a perennial water-supply. It is unlikely that all of these conditions can be satisfactorily fulfilled near the settler's own village because most of the good land will have already been taken up. This means that he will have to go to some remote part of the district where his marketing difficulties will be increased and he will be cut off from his village associates.

The work of supervising ex-students after they have settled on their own farms will be considerably increased if they are widely scattered. The students themselves are fully alive to these problems and are seeking their own solution. For example, students of the 1943 class, before leaving the school, had approached their village councils for assistance to obtain an area of land sufficient to enable them to settle in groups of 4 or 5. This system has many commendable features; the boys not only continue their association as educated farmers, but form the nucleus of a new rural society with many social and economic advantages. In addition, their post-school administration will be considerably facilitated.

Health of the students.—The Government Medical Officer, Ibadan, has been asked to visit the school once a year to examine the new class of students and report on the general health of the second-year students as well. Except for minor complaints the general health of the boys during the past 3 years has been satisfactory. As the students are now coming straight from elementary schools their ages usually range from 15 to 18 years. During their first year at the Farm School they are provided with full board. Their meals are prepared by a cook and taken at regular hours. A good diet and hard work certainly improve their physical condition, and by the end of the first year of their training the change in their development is very noticeable. During the second year of the course, when they enjoy a greater measure of independence, they provide their own subsistence from a monthly allowance paid from the scholarship account.

Finance.—The Oyo Native Administration acquired the site for the Farm School and pays for the erection and maintenance of all buildings. The Agricultural Department has to date made an annual grant of £60 per student in respect of the three classes admitted during the period 1942-4, inclusive. Since the first class of students left the school in January 1943 the cost of living has risen considerably and a more liberal allowance has had to be made for subsistence during training. In addition the cost of buildings and livestock has also increased so that the original estimate of the cost of training and capitalizing a settler has had to be revised. The present charges are approximately as follows:

	£
Subsistence for 3 years at £9 per annum	27
Cost of dwelling-house for settler	10
,, ,, houses for livestock	10
,, ,, cattle (3 cows and 1 bull at £7 each)	28
Tools and equipment	2
	£77

If a student adopts a system of farming involving the use of cattle-drawn implements he also requires one extra bull, a plough, a larger stock-pen, and some allowance for the cost of stumping land preparatory to ploughing. The approximate cost of these items is 1 bull £7; 1 plough £5; extra cost of buildings for stock £2; and allowance for stumping £3; total £17.

These items, together with the charges listed above, bring the total capital required for a mixed farmer with a plough to £94.

To some extent the situation has been remedied through the provision of a loan scheme for settlers' buildings, by the Oyo Native Administration. In future, settlers requiring money to build a dwelling-house will not draw on their scholarship grant for this purpose but will apply for a loan from the Native Administration, which will be responsible for obtaining necessary guarantors and collecting repayments when due. Loans are granted for dwelling-houses at 3 per cent. interest per annum and the capital is repayable in annual payments of one-tenth, two-tenths, three-tenths, four-tenths, at the end of the second, third, fourth, and fifth years respectively.

Thus a settler is not called upon to make any repayment until he has completed 2 years on his farm, when he should, without prejudice to his work, be able to meet his liabilities on the scale laid down. When possible, a student is encouraged to obtain assistance from his family to build his house in preference to obtaining a loan. If such a course is impracticable he is advised to borrow the minimum amount necessary. Unless there are exceptional circumstances no loans are granted for dwelling houses in excess of £10.

All of the first payments in respect of the loans granted for dwellings to the 1942 class have been duly paid up.

Selection of students for training and settlement.—Opinion is not unanimous concerning the best type of student for training and settlement. This is an important question, but the scheme has not been in operation long enough to enable any definite conclusions to be drawn. Up to 1944 only boys who had received an elementary education were admitted to the school, but in 1945 it was decided to recruit equal numbers of educated boys and illiterate youths with the object of exploring more fully the problem of the best type of student for training. All of the uneducated boys were drawn from the neighbouring farming community and were mostly sons of farmers. They had already had considerable experience of local farm practice through working on their parents' farms. In comparison with their educated contemporaries they were already well adapted to rural life and certainly displayed a greater aptitude for manual work. It remains to be seen, however, whether their lack of schooling will subsequently prove to be a handicap when they begin settlement on their own farms and will be required to exercise judgement and discretion in the best use of their capital and other farming opportunities.

Some major difficulties.—There are many conditions which must be fulfilled before a boy can become a successful farmer, but unless he has at the outset an honest liking for rural life coupled with a willingness to engage in manual work there is little hope of his ever making a successful livelihood from the land. Up to the present very few boys in the elementary schools in the Oyo district appear to possess these attributes. It was hoped that the scholarship scheme might attract some of the brighter boys to take up farming, but the response so far has been below expectations. There are several reasons for this. Firstly, it has not been possible as yet to show any concrete results from the school and any inducements which may be offered have not been supported by facts. Until sufficient time has elapsed for Farm School settlers 'to make good' the scheme will continue to be regarded with suspicion. Secondly, it must be remembered that the elementary schoolboy goes to school with the object of obtaining a better livelihood than he could otherwise secure in his village. On the completion of his schooling he quite naturally seeks some form of salaried employment in the town in preference to any other occupation. If he fails to achieve this end he is often content to live a life of idleness rather than return to the land. Thirdly, the parents and schoolmasters are not yet convinced that there is anything to be made out of farming and will frequently discourage boys from taking up farming even

when they show an inclination to do so. The success of the Farm School Scheme must obviously depend on its ability to produce convincing evidence that farming can offer opportunities as a career at least as good as the various types of salaried employment which are normally open to boys with an elementary education.

General considerations.—It is emphasized that the Farm School is an experiment in vocational training in farming. The primary objects of determining the best methods of training boys and settling them on the land and the amount of capital necessary for this purpose have, to some extent, been determined. The process is necessarily slow since under the present scheme of training it takes 2 years to train a boy at the school, and he can hardly be expected to produce any substantial results from his work until he has completed at least 2 years' farming on his own. Thereafter, there should be a progressive rise in his income as his stock matures and increases in number, and as his experience and aptitude for the work develop. For these reasons it is unlikely that the value of the scheme can be fully judged in respect of any one class until the settlers have completed 4 or 5 years' work on their farms, that is 7 years from the date of admission to the Farm School.

Only students of one class have so far had any experience of farming on their own. They left the school in 1943, and during their first year they were mainly concerned in clearing bush and opening up their farms. This involved much hard work, but it was successfully completed by the end of the year when every settler had at least 2 acres under annual crops. At this stage their farms provided little more than the essential food requirements for themselves and their families, but during the following year most of the settlers extended their farms to 3 acres or more and were then in a position to sell some produce from their farms. As part of their training they were taught to keep a simple form of cash-book showing all receipts and payments during the year. At the end of 1944 the settlers were called upon to submit a statement of their returns for the year, and at the same time a valuation of their live stock was also made. This information is summarized below.

Although the incomes from the settlers are very variable, they do provide some interesting indications on which branches of their farms' cash returns are obtained. The fact that the settlers were reluctant to give details of their incomes, probably because they feared individual tax-assessment or that rent might be charged, suggests that the information given is unlikely to be an overstatement, and in all probability their real incomes are in excess of the amounts declared. It is also important to remember that besides providing the cash returns stated, their farms have supplied subsistence for the farmer and his family. The financial status of the settlers is therefore by no means unsound and in most cases can be regarded as considerably better than that of the local farming community. In addition, the capital value of their live stock has in several instances nearly doubled during the two years they have been farming.

It must be admitted that the sheet-anchor of all the cash receipts has been income derived from the sale of birdseye chillies, but this is not a

Summary of Cash Returns from Farm School Class recruited January 1942 after Two Years' Settlement. Returns are for the year 1944

Settler No.	Where Farming	Analysis of Cash Returns from Farms: Bird's-eye Chillies	Native Chillies	Cassava	Maize	Beans	Egusi	Poultry & eggs	Milk	Misc.	Total
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1	*Farm School*	12 10 0	..	0 5 0	0 14 0	1 5 0	2 12 6	1 2 9	1 5 0	..	19 14 3
2	,,	8 15 0	2 12 6	0 7 9	0 8 0	0 8 6	0 6 9	0 18 0	1 18 3	2 4 4	17 19 1
3	,,	10 10 0	..	0 15 6	0 5 10	0 16 0	..	0 12 1	0 12 6	..	13 11 11
4	,,	9 0 0	0 2 0	0 4 0	0 9 0	..	..	..	..	..	9 15 0
5	,,	7 15 5	..	0 2 6	0 4 4	0 6 0	0 3 6	..	0 5 9	..	8 17 6
6	,,	5 19 6	..	..	..	0 10 0	0 4 6	..	..	0 12 10	7 6 10
7	,,	4 10 0	..	0 9 0	0 4 0	0 3 6	0 3 0	..	..	0 6 0	5 15 6
8	*Ilora*	3 10 0	..	0 4 6	1 5 0	0 11 0	0 1 3	0 1 5	..	0 6 0	5 19 2
9	*Oluwatedo*	9 7 0	0 3 6	..	0 6 0	0 13 0	..	..	..	0 11 0	11 0 6

Summary of Live-stock Mortality and Increases at the Suru Lere Settlement of the Farm School for May 1943–March 1945

Settler No.	No. of Cows issued	Estimated Value	Losses: Cows	Losses: Calves	Cattle on hand end of March '45: Cows	Bullocks	Heifer Calves	Estimated Value Stock March '45	Estimated Capital Increase
		£ s. d.						£ s. d.	£ s. d.
1	3	14 0 0	..	..	3	..	3	27 0 0	13 0 0
2	3	14 0 0	1	..	2	2	1	21 0 0	7 0 0
3	3	14 0 0	..	..	3	..	2	24 0 0	10 0 0
4	3	14 0 0	..	..	3	..	2	24 0 0	10 0 0
5	3	14 0 0	..	1	3	1	3	30 0 0	16 0 0
6	3	14 0 0	..	..	3	1	2	27 0 0	13 0 0
7	3	14 0 0	..	..	3	..	..	18 0 0	4 0 0
8	2 & 1 *bull*	15 0 0	..	..	2	1	1	21 0 0	6 0 0
	Sows		*Sows*	*Piglings*	*Sows*	*Boar*	*Piglings*		
9	3	2 8 0	1	9	3	1	4	5 8 0	3 0 0

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privilege enjoyed only by settlers, since the crop is grown by most farmers in the district, though possibly not quite so extensively as by some of the settlers. Sales of milk and vegetables also appear in the list of receipts. These are new sources of income which are not obtained by local farmers. There is good reason to believe that in subsequent years the incomes of settlers will substantially increase, for as yet the most important branch of their farms, live stock, has yielded no returns. When sufficient time has elapsed for their cattle to increase in number there should be a regular annual income from this source at least equal to, if not greater than, the sum total of all the other products from the farm.

In attempting to judge the success of the Farm School to date there would appear to be real grounds for assuming that the settler who is prepared to work hard and make the fullest use of the opportunities open to him may reasonably expect to make an income from his farm at least not inferior to that which he might have obtained from some form of salaried employment.

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SOLWAY PINE: A MARASMIC CONDITION IN LAMBS IN CERTAIN DISTRICTS OF KIRKCUDBRIGHTSHIRE

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WITH PLATE 3

FOR many generations Kirkcudbrightshire flockowners have known that lambs do not thrive on the pastures of the Criffel Range and its slopes, including the parishes of Kirkgunzeon, New Abbey, Kirkbean, Southwick, and Colvend, and on a second area some 10 miles distant, the east-lying slopes above Auchencairn Bay. The districts are very well defined and the flockowners concerned know that, if they shift their lambs on to other farms in the neighbourhood, they will recover. This local custom of changing the sheep off the 'pining' farms on to known 'non-pining' farms nearby, which are of a different soil type, has been in vogue for over a century as is well detailed by MacLelland [1] and McCulloch [2]. Thus, even at a very early date the disease was related to the soil type and the herbage.

The condition is that of a progressive debility. The growth of the lamb is markedly retarded and it soon presents a stunted, unthrifty appearance accompanied with a dry, lustreless, and broken fleece, and a serous discharge from the eyes. Finally, as a result of extreme weakness, the animal is unable to rise and death ensues. The mortality-rate may be very high but varies from year to year. From clinical symptoms Solway pine could not be differentiated from any of the other pining conditions in lambs, such as worm-infestation or the pining condition common in Ross-shire and the north of Scotland.

Since all the known history and data concerning the disease appeared to relate the cause to the soil or pasture, samples were obtained from both the pining farms and those on which recoveries were obtained in the district round Auchencairn Bay. Analysis of these samples for major constituents revealed a general mineral deficiency especially of magnesium and potassium. Research work centred round this finding for a considerable time, but it was eventually shown that if the deficiency of minerals in the diet was obviated by feeding these minerals as dietary supplements to both ewes and lambs the occurrence of pining was not significantly reduced, although on several farms it seemed to improve the general condition of the sheep.

Owing to the lack of success in this line of investigation it was decided to make a more comprehensive examination of the soil and pasture of the pining areas. The results of the analyses are summarized in Table 1.

TABLE 1. *Chemical Analyses of Solway Soils and Pastures*

SOILS

Farm and field	pH value	Loss on ignition as per cent. oven-dry soil	0·5N Acetic-acid extract						
			mg. per 100 g. soil (air-dry)					p. p. m.	
			P_2O_5	K_2O	CaO	MgO	MnO	Co	Ni
A . .	5·45	17	3	9	120	9	3·2	0·37	0·64
B . .	6·10	12	12	7	300	18	4·3	0·12	0·76
C . .	6·30	7	15	3	180	8	3·9	0·20	0·44
D . .	5·50	14	3	6	150	7	3·6	0·18	0·39
E . .	5·30	16	4	22	170	23	4·6	0·38	1·54
F . .	5·60	13	10	6	140	7	3·4	0·17	0·45
G 1 . .	5·20	21	4	8	110	7	1·6	0·19	0·68
G 2 . .	5·85	14	6	6	240	6	2·3	0·27	0·64
H . .	5·35	13	7	6	130	6	3·2	0·14	0·51
I . .	6·45	10	8	3	300	6	1·1	0·12	0·63
J . .	5·70	11	8	7	170	6	4·3	0·17	0·57
K . .	5·25	10	13	5	110	7	4·3	0·10	0·40
L 1 (1944) .	5·15	27	2	10	240	17	1·6	0·13	0·57
L 1 (1943) .	4·80	35	2	10	210	19	1·0	0·15	0·56
L 2 . .	4·90	30	1	13	180	22	1·3	0·09	0·41
L 3 . .	5·60	12	9	5	160	8	1·5	0·14	0·41

PASTURES

Farm and field	Percentages (100 per cent. dry-matter basis)					Hydrochloric-acid extract of ash percentages (100 per cent. dry-matter basis)						Parts per million (100 per cent. dry-matter basis)			
	Crude protein	Crude fibre	Ether-extract	Total ash	N-free extract	P_2O_5	CaO	K_2O	MgO	Na_2O	MnO	Co	Ni	Mo	Fe
A . .	17·82	18·76	2·48	7·95	52·99	0·79	0·48	2·30	0·33	0·38	0·012	0·08	1·15	1·53	86
B . .	21·42	19·34	4·31	10·06	44·87	0·80	0·87	2·65	0·39	0·32	0·012	0·02	0·45	11·6	64
C . .	23·19	16·17	3·85	9·82	46·97	0·85	0·88	1·95	0·38	0·49	0·009	0·03	0·66	5·08	55
D . .	16·38	21·19	3·16	9·70	49·57	0·63	0·59	2·20	0·26	0·31	0·018	0·03	0·41	1·68	55
E . .	14·19	28·10	2·42	9·85	45·44	0·71	0·79	3·55	0·33	0·17	0·031	0·20	1·76	0·83	57
F . .	15·46	27·52	2·34	7·46	47·22	0·69	0·43	1·75	0·22	0·27	0·013	0·03	0·43	1·43	74
G 1 . .	25·23	19·86	2·98	8·42	43·51	0·82	0·65	2·60	0·36	0·30	0·018	0·04	0·78	1·31	58
G 2 . .	21·26	18·74	2·74	8·02	49·24	0·79	0·74	2·40	0·37	0·53	0·018	0·05	0·73	2·64	69
H . .	15·78	25·95	2·46	7·92	47·89	0·78	0·53	2·15	0·34	0·73	0·017	0·02	0·52	1·14	51
I . .	24·15	19·08	2·81	10·61	43·35	0·93	0·83	3·00	0·34	0·66	0·013	0·04	0·62	4·23	64
J . .	17·29	24·10	2·97	8·10	47·54	0·62	1·14	1·10	0·32	0·30	0·018	0·02	0·88	0·73	38
K . .	20·34	22·29	3·56	7·18	46·63	0·64	0·96	1·35	0·28	0·24	0·011	0·04	0·56	1·03	239
L 1 (1944) .	19·17	20·37	3·12	9·10	48·24	0·72	0·59	3·35	0·35	0·30	0·038	0·04	0·50	0·98	82
L 1 (1943) .	16·48	22·56	3·16	10·42	47·38	0·83	0·43	3·04	0·28	0·15	0·036	0·06	0·94	0·77	85
L 2 . .	19·26	18·52	2·98	9·86	49·38	0·85	0·71	3·38	0·20	0·10	0·016	0·04	0·46	1·15	125
L 3 . .	20·41	21·48	3·56	9·12	45·43	0·84	0·59	2·54	0·27	0·25	0·013	0·11	0·83	0·50	210

Farms A to E are in the Auchencairn district and F to L in the Criffel area. The numbers 1, 2, &c., refer to particular fields on these farms.

The data in the Soils section show that there is a considerable variation in the acidity conditions and lime-contents of the different soils, the majority being rather acid. The magnesium-contents more or less follow those of lime. Likewise, both phosphate and potash are low, the phosphate being, if anything, lower than the potash. The manganese values are well within the normal range. There are only two soils, A and E, the cobalt-contents of which could be termed adequate. From data already collected [3] it would appear a general rule that soils containing less than 20–30 parts per hundred million of readily-soluble cobalt are liable to be cobalt-deficient, i.e. lambs are likely to 'pine' when put to pasture grown on these soils. Farm A is a farm on which pining occurs on some fields but not on others, being just on the borderline of what local stockowners call 'the healthy area'. Farm E was taken as a control farm for the Auchencairn area, since neighbouring farmers sent their lambs to winter there, as it had the reputation of being able to cure 'pine'.

In discussing the pasture values the first point of interest is in those constituents which determine the nutritive value of the herbage. The protein and starch equivalents of most of the samples would be of the order usually associated with high-grade pasture. From the values given in Table 1 there would be no reason to expect that lambs would do anything else but thrive on such pastures. Although there is a large variation in the major mineral constituents and several of the samples are low in several minerals, especially calcium, potassium, and sodium, the deficiencies of these elements are not of a dangerous order. The cobalt-contents are all rather low except L 3, where there is evidence of soil contamination from the Fe figure. From research work done in other areas it is believed that all pastures with a cobalt-content below 10 parts per hundred million may be deficient in cobalt. The majority of the samples detailed above are of the order of 3 to 5 parts per hundred million.

Since these pasture samples had a cobalt-content of the same order as those from the cobalt-deficiency pining-area of Easter Ross, a cobalt-dosing experiment was carried out in 1944. Two groups of lambs of equal age were chosen at random from the flock of one of the farms on the foothills of the Criffel, near Kirkgunzeon (Farm L in Table 1). Each group at the commencement of the experiment numbered 40, but owing to a few deaths from causes unconnected with the experiment the control group numbered 36 and the cobalt-dosed group 38 within a few weeks. Each lamb of the cobalt-dosed group received by the mouth a dose of 7 mg. of cobalt as cobalt chloride each week. Dosing began on May 27 and was continued till September 9. The lambs were weighed on July 9 and September 9. One of the control group died of 'pining' before the second weighing. The weights are given in Table 2.

The lambs of the control group gained only 5·2 lb. during the two months, July 9 to September 9, whereas the lambs receiving a weekly

dose of cobalt gained 21·4 lb. Moreover, although not one of the cobalt-dosed group showed any of the clinical symptoms of 'pine', 10 of the control group were in an advanced stage of the disease by September 9.

This highly significant result demonstrated that the addition of cobalt *per se* to the diet was capable of preventing the onset of 'pining' in the young lambs on this farm.

To confirm the results obtained in 1944, and following the successful prevention of cobalt-deficiency in Ross-shire and the north of Scotland by top-dressing pastures with cobalt-rich fertilizers, it was decided in 1945 to carry out a cobalt-manuring experiment in the Solway area. The farm selected was again 'L' of Table 1 and the field (L 3) one of 22 acres in extent.

TABLE 2. *Difference in Live-weight Gain between Control Group and Group receiving a Weekly Dose of 7 mg. Cobalt*

Group	*Date*	*No. of lambs*	*Range of weights lb.*	*Mode lb.*	*Total weight lb.*	*Mean weight lb.*	*Standard deviation from the mean weights*	*Diff. in mean weights July 9 & Sept. 9 lb.*
Control	July 9	36	20–50	36–40	1376	38·2	±5·8	
,,	Sept. 9	35	28–65	41–45	1521	43·4	±9·07	+ 5·2
Cobalt-treated	July 9	38	31–52	41–45	1609	42·3	±4·81	
,,	Sept. 9	38	42–77	66–70	2422	63·7	±8·06	+21·4

The soil of this experimental field was a well-drained brown to dark-brown medium loam derived from a glacial drift consisting mainly of local granite, but containing a discernible admixture of graywacke, mudstone, and sandstone fragments. The field had been well treated with lime and fertilizers since the 1943 samples were taken, as a result of which the soil had a pH value of approximately neutrality, was reasonably well supplied with phosphate but slightly low in readily soluble potash. As seen from Table 1 the pasture of this field had a cobalt-content slightly higher than the rest of the fields of this farm and neighbourhood but was considered cobalt-deficient on the basis of the soil values.

It was arranged that the field be divided into two equal areas by an impassable wire-fence. One half received a top-dressing of superphosphate at the rate of 1½ cwt. per acre. The other half was also top-dressed with superphosphate at the rate of 1½ cwt. per acre, but 2 lb. of cobalt sulphate was mixed with each 1½ cwt. of superphosphate applied. The top-dressing was applied on April 2 and 10 ewes, each with twin-lambs, were placed on each half of the field on April 25.

In Table 3 data are given to show the increase in the cobalt-content of the pasture of L 3 due to the cobalt top-dressing. The samples for analysis were taken on July 11, 14 weeks after being top-dressed.

The value for the cobalt-content of that half of the field which received no cobalt is comparable with that given for this field in Table 1, and is

TABLE 3. *Increase in Cobalt-content of Pasture due to Cobalt Top-dressing*

Sample	Percentages (100 per cent. dry-matter basis)					Hydrochloric-acid extract of ash percentages (100 per cent. dry-matter basis)						Parts per million (100 per cent. dry-matter basis)			
	Crude protein	Crude fibre	Ether-extract	Total ash	N-free extract	P_2O_5	CaO	K_2O	MgO	Na_2O	MnO	Co	Ni	Mo	Fe
No cobalt .	18·42	23·41	3·08	11·14	43·95	0·91	1·15	1·90	0·33	0·52	0·011	0·09	0·57	1·33	110
Cobalt-treated .	20·76	22·96	3·42	10·56	42·30	0·80	1·25	1·10	0·32	0·65	0·008	0·38	0·44	2·10	115

TABLE 4. *Difference in Live-weight Gain between Control Group on Cobalt-deficient Pasture and Experimental Group on Pasture top-dressed with Cobalt*

Group	Date	No. of lambs	Range of weights lb.	Mode lb.	Total weight lb.	Mean weight lb.	Standard deviation from the mean weights	Diff. from initial mean weight lb.
Control . . .	April 25	20	14–20	16–20	327	16·4	± 2·0	..
,, . . .	June 27	20	32–52	41–45	836	41·8	± 5·21	+25·4 (9 wks.)
,, . . .	Aug. 9	19	32–65	41–45	890	46·8	± 10·2	+30·4 (15 wks.)
On cobalt-dressed pasture	April 25	20	11–18	11–15	268	13·4	± 2·1	..
,, ,,	June 27	19	40–58	51–55	933	49·1	± 5·38	+35·7 (9 wks.)
,, ,,	Aug. 9	19	58–78	71–75	1275	67·1	± 6·3	+53·7 (15 wks.)

again rather higher than usually considered to be a pining level. It will be seen that there is a substantial rise in the cobalt-content of the cobalt-treated half in keeping with that obtained in the Ross-shire experiments [4] with a similar top-dressing. The obtaining of representative pasture samples from fields on which stock are grazing is always a problem to the research worker, since the herbage of suitable length for sampling is usually that which has been left uneaten by the stock and therefore not truly representative of what has been eaten. In order to avoid this error we usually fence off small areas in such a manner as to prevent the stock having access to them. This allows of the total summer growth on the sampling area being obtainable untrampled and also uncontaminated by the dung of the grazing animals. This was the method adopted in the present experiments.

The ewes and lambs were kept continuously on the field on their respective sides of the fence till August 12, and the lambs were weighed on April 25, June 27, and August 9. The weights are summarized in Table 4.

From Table 4 it will be seen that even at 9 weeks of age the lambs on the cobalt-dressed pasture had already gained an average of 10 lb. live-weight over those on the other side of the fence, and that by 15 weeks the gain had increased to over 23 lb. From the 9th to the 15th week the control group on the average gained only 5 lb. and even this small gain is seen from the mode column to be mostly due to one or two members of the group making almost normal growth. It would appear, therefore, that lack of cobalt may begin seriously to retard growth at from 6 to 9 weeks of age in the Solway area.

The results of the manuring experiments carried out in 1945 have confirmed the results of the cobalt-dosing experiment of 1944. There would now appear to be ample evidence that cobalt added to the diet of the lamb in the above-mentioned areas of Kirkcudbrightshire prevents the lambs from pining and the consequent large loss in live-weight. In Fig. 1 (Plate 3) is shown a photograph of the carcasses of 3 of the lambs of the 1945 experiment; A and C were *typical* members of the group on the cobalt-manured half of the field and B of the group on the cobalt-deficient half. The photograph was taken on October 12, when the lambs were almost 6 months old. Immediately before being killed on that date A and C weighed 75 and 78 lb. respectively, whilst B weighed only 31 lb. (The weights given in Table 4 show that B must have lost weight since August 9.) The carcass weights of A and C were 33 and 35 lb. respectively and that of B 10 lb.

On August 12 all the lambs on the cobalt-deficient half of the field with the exception of 3 (of which B in Fig. 1 was one) were transferred to another field also cobalt-deficient and 3 weeks later were returned to field L 3, but to the cobalt-dressed half. They all made a slow but uneventful recovery and when seen on November 1, not one was showing any clinical symptoms of pine and, though not nearly as big as the lambs which had been on the cobalt-dressed pasture from birth, they were thriving. It might be emphasized that lambs once stunted in growth for lack of cobalt make only slow progress to normal once cobalt is

administered, and not a spectacular quick recovery as has been stated by some authorities.

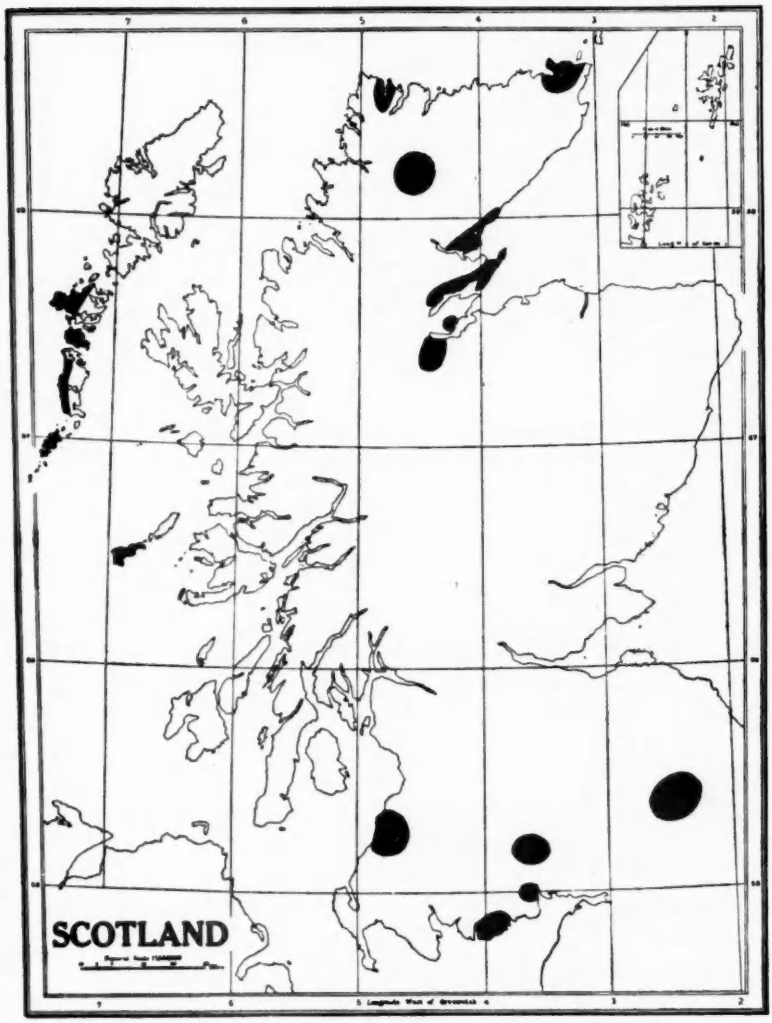

FIG. 2. Known cobalt pining areas in Scotland.

As mentioned previously, the pasture of the field on which this experiment was carried out had the highest cobalt-content of all the fields on the farm, and one which was just above the high limit, previously accepted, for cobalt-deficient herbage. The experiments described above

have shown that lambs will pine on a pasture of even this cobalt-content. We have still to obtain information how factors such as herbage species, quality of sward, density of stocking, and, above all, the digestibility of the cobalt-compound in the plant, affect the assessment of cobalt-deficiency of any particular pasture.

Since cobalt-deficiency has been established in the pastures of the above-mentioned districts of the Solway it is of interest to observe how widespread in Scotland are the areas of cobalt-deficient soil and herbage. The known cobalt-deficient areas are mapped in Fig. 2.

From Fig. 2 we can surmise that the loss to stockowners in Scotland due to cobalt-deficiency has been very great, and still is unless means are taken to prevent it, either by feeding cobalt-rich mineral mixtures or, where possible, if soil type and stock husbandry permit, by top-dressing with cobalt-rich fertilizers. Further investigations, it is hoped, will delineate other cobalt-deficient areas, and also those areas where the cobalt-status of soil and pasture, whilst not so low as to cause severe pining, may yet result in great economic loss to Scottish sheep-farmers.

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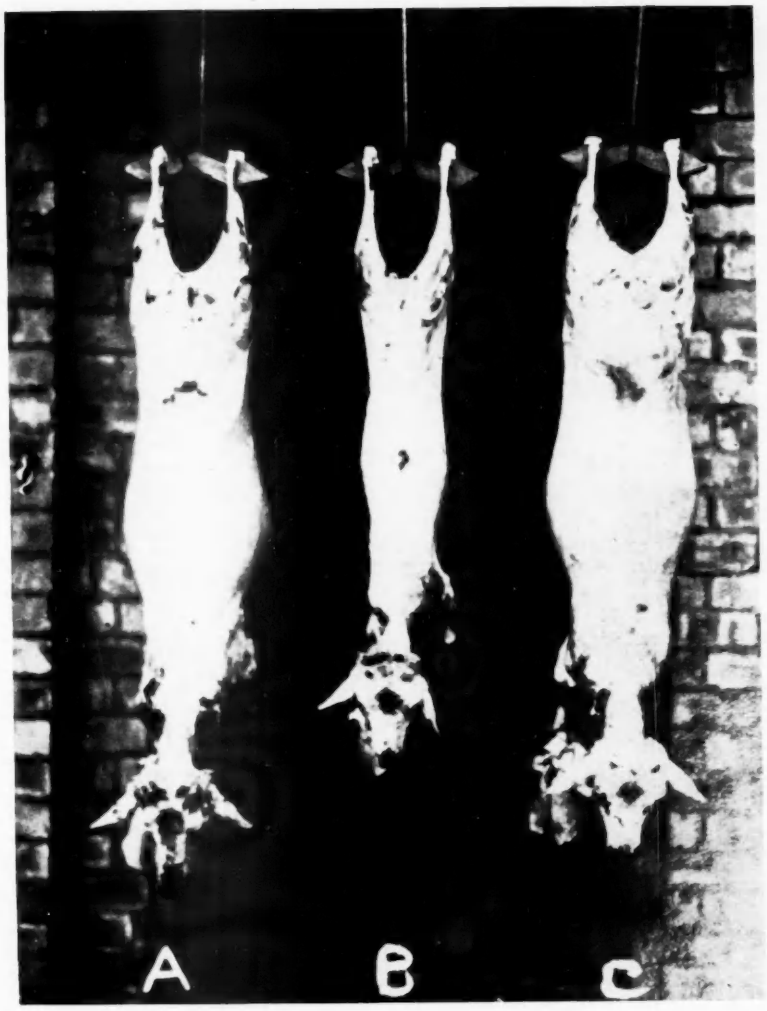

* 75	31	78
† 33	10	35

* Live-weight in lb. 12 Oct. 1945

† Carcass weight in lb. 12 Oct. 1945

FIG. 1. Carcasses A and C of lambs fed on cobalt-manured pasture and of B on unmanured pasture

BREEDING COTTON RESISTANT TO BLACKARM DISEASE

(*Bact. malvacearum*)

PART I: INTRODUCTORY

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BLACKARM, a term that includes Angular Leaf-spot, Bacterial Blight, and Bacterial Boll Disease, is caused by *Bacterium malvacearum*, E. F. Sm. The disease is ubiquitous in Africa wherever cotton is grown, though it is only of very minor importance in Egypt. It has also been reported in U.S.A., Brazil, Argentine, West Indies, Russian Central Asia, India, Australia, Korea, and Fiji, and in several of these countries it causes a serious loss of crop.

In Uganda, Blackarm is a major limiting factor in cotton production and detailed examination will probably show that this also applies to Tanganyika. In Kordofan Province of the Anglo-Egyptian Sudan it causes widespread damage each season and preliminary tests indicate that a moderate attack can reduce the yield of American Upland by at least 30 per cent.

In the three irrigated regions of the Sudan (the Gezira,[1] the Gash Delta, and Tokar) 'Egyptian' cotton is grown. Of these areas, the Gezira is by far the most important. Blackarm was first recorded there in 1922, though it may have been present in other parts of the country for many years before that date. Both the climatic conditions and the topography of the Gezira favoured the spread and survival of the disease. Moreover, the variety, Sakellaridis,[2] grown in this district is very susceptible to blackarm attack.

With the construction of the Sennar Dam and the extension of cotton-growing in the Gezira, this area played an increasingly important part in the economics of the Sudan. The arrival of blackarm and the consequent loss in production created, therefore, a serious problem which was only partially solved by the adoption of drastic and costly measures of plant-hygiene.

The urgent need of procuring strains resistant to the disease was obvious, but a preliminary survey had shown that all 'Egyptian' strains were highly and equally susceptible (though some were able to make a better recovery from the disease than others). It was, therefore, evident that selection within the Sakel genotype was likely to be useless and that the only hope of success lay in transferring thereto, by backcrossing, the resistance occurring in certain American Upland (*G. hirsutum*, L.) and Punctatum (*G. hirsutum* var. *punctatum*) cottons.

[1] The Gezira is an area lying between the Blue Nile and the White Nile and irrigated from the Sennar Dam.

[2] Sakellaridis, commonly called 'Sakel' is a variety of *G. barbadense*, L.

These transferences have now been successfully carried out and 'Egyptian' strains, carrying the main genes governing blackarm resistance, are in cultivation.

In breeding for blackarm resistance in American Upland cottons, suitable for the rain areas of the southern Sudan, experience has been gained of the reaction of resistant types under varied climatic conditions. Blackarm-resistant Upland varieties have passed through the variety-trial and spinning-test stages and have been accepted as commercial types for Equatoria and Kordofan Provinces, the two main areas of rain-grown cotton.

Sudan experience has proved the economic value of the methods of blackarm-resistance breeding employed and it is felt that the time has come to publish details for the use of plant-breeders in other countries.

Blackarm Disease of Cotton

B. malvacearum, Sm., is described by Massey [1] as 'a pleomorphic, strictly aerobic, highly motile, slime-producing, moisture-loving organism'. The bacterium is spread by rain and wind and it attacks the whole of the aerial portion of the cotton plant except the flowers.

On the leaves, entry is through the stomata and, after an incubative period ranging from 4 or 5 days to 3 weeks according to climate and shade, typical 'water-soaked' lesions begin to appear on the lamina. In a susceptible type these lesions increase in size up to 3 or 4 mm. across and often coalesce. They are angular, being bounded by the veins, and translucent at this stage, drying later to a sooty black in Egyptian types of cotton or to a brownish-black in American varieties. Frequently the diseased areas spread alongside the bigger veins, making bands of water-soaked tissue which later dry black, or brownish-black, according to whether the variety is Egyptian or American.

Direct infection of the *stem* may occur through the agency of rain-splashes from diseased material, but it also frequently takes place from the leaf via the petiole. Another frequent method of spread is by surface-wash [2]. Large water-soaked lesions appear on susceptible types and, in a severe attack, the stem may become girdled and snap off. Branches may also be girdled and killed by the disease, resulting in a direct loss of crop. In Uganda, tips of branches are also frequently invaded by the disease and killed.

Bolls are attacked and the bacteria find their way through the intervening tissues to the seed, so that the lint and fuzz are covered with a bacterial slime. These bacteria on the seed coat form a major source of infection of the new crop.

The symptoms and life cycle of blackarm are more fully described by Massey [1, 3, 4, 5, 6] and the method of spread by Andrews [7, 8, 9] and Hansford *et al.* [2], whilst Butler [10], Hewison [11], and Hansford [12] give a good idea of the damage this disease can cause.

The possibility of the existence of distinct *biologic races* of *B. malvacearum* merits careful consideration. If such races exist, the Sudan work on resistance may be of but limited application. In the past, cotton seed has frequently entered the Sudan from America, the West Indies, and

India without undergoing any seed sterilization of a type likely to remove *B. malvacearum* completely. It is therefore likely that blackarm bacteria of American, West Indian, and Indian origin are present in the Sudan. With regard to other African 'strains' of the disease, cotton seed from Egypt and from East, South, and West Africa has, in the past, been imported without effective sterilization. Furthermore, in 1940, 3 tons of seed of SP 84 and 200 lb. of SP 20 were imported into Equatoria from Uganda and sown without sterilization, so that if any biologic races of the disease exist in Uganda these will certainly also occur in Equatoria. Both Upland and *barbadense* types bred for resistance at Shambat (near Khartoum) maintain their characteristic resistance to blackarm when grown in Equatoria. These facts go far to prove that, even if biologic races of the disease exist, the key genes on which the Sudan work is based still confer resistance under conditions in which *B. malvacearum* from widely different sources is likely to have been present.

Genetical considerations.—The genetic basis of blackarm resistance and a survey of its occurrence in Gossypium will be found in a series of papers published elsewhere [13, 14, 15, 16]. Two of these [13, 15] give details of the transference to 'Egyptian'[1] types of the main genes for resistance from American Upland and punctatum. Further details of the genetic and breeding aspect will be found in the writer's annual reports for the seasons 1938–9 to 1944–5 [17, 18, 19, 20, 21, 22].

From the point of view of the breeder interested in producing blackarm-resistant *barbadense* types the position is as follows. *G. barbadense* has been shown, in general, to be fully susceptible [14] and, though one resistant plant was found, this was later [15] ascribed to outcrossing to *G. hirsutum* followed by chance backcrossing in the field. The inclusion by J. B. Hutchinson [23] of *G. darwinii* as a variety of *G. barbadense* adds a resistant subdivision to the species, since blackarm-resistance has been found in *darwinii* [20]. During a routine examination of blackarm symptoms on the Empire Cotton Growing Corporation's Type Collection from Trinidad (now being grown in the Sudan), a further resistant variety was found in the *G. barbadense* group. This variety, BP 1—1 (Grenadines White Pollen), shows marked resistance, but no genetic analysis has yet been made.

In American Upland types any worthwhile resistance has always been found to be due to a single gene, which has been called B_2. Very occasionally another gene for resistance is present, B_1, but this gene is weak and is of little value in American Upland breeding-work. Furthermore, B_1 is barred for use in some American types because of its secondary action in producing pronounced dwarfing [16] when it is transferred to such types.

The only other resistance gene so far isolated that is important from the breeding point of view is B_3. This occurs in certain *G. punctatum* (= *G. hirsutum*, L., var. *punctatum*, Sch. *comb. nov.* J.B.H.) types.

[1] 'Egyptian', Sea Islands, and American-Egyptians all belong to *G. barbadense*, and the term *barbadense* is used throughout this paper to refer to these varieties indiscriminately.

The blackarm-resistance factors, B_1, B_2, and B_3.—B_1. This is a fully dominant, weak gene originally obtained from the Uganda variety, B 31. B_1 is unlikely to be of much value in American Upland breeding. Susceptible Upland shows a slight degree of resistance as compared with *barbadense* and B_1 adds little to this. When transferred to *barbadense*, B_1 confers a degree of resistance slightly greater than that typical of susceptible Upland types. This has been figured in previous papers [13, 15] and graded as '10·1' on a scale in which '0' represents immunity, '10' full American susceptibility, and '12' full *barbadense* susceptibility ('11' is absent from this system of grading). Grade '10·1' is defined [15] as 'lesions similar in size to "12" or rather smaller, but slower developing and seldom coalescent; angular and black when dry but often have a blurred edge'. The definition refers to the appearance of leaves of *barbadense* plants which have been sprayed with blackarm inoculum and which are examined at the time when the sprayed leaves of the susceptible *barbadense* control are showing their maximum infection. Shortly after this, the sprayed leaves on the susceptible type fall, and, under conditions of high humidity (especially when rain has fallen during the period between spraying and grading), the '10·1' lesions on the B_1 plants begin to coalesce down the veins and the typical '10·1' appearance is lost.

Shambat experience indicates that B_1 is of little value in Upland types, since B_1 Uplands are little more resistant than ordinary susceptible Uplands. Because of this, coupled with its association with the character 'dwarf-bunched' [16], Upland types carrying B_1 have not been studied by the writer under rainfall conditions.

On a *barbadense* background, B_1 has an additive effect when used in conjunction with B_2 so that plants carrying both factors are slightly more resistant than those carrying B_2 only (and, of course, considerably more resistant than those carrying B_1 only). It is probable that B_1 has an additive effect when used in conjunction with B_2 in an Upland type, since Uganda B 31, which carries both factors, is more resistant than Upland varieties carrying B_2 only. It seems likely, however, that this added resistance is largely due to the presence, in B 31, of modifying factors which increase the effect of B_2 [14].

B_2. This is a strong, fully dominant factor originally obtained from the Uganda variety, B 31, but occurring, also, in several other Upland varieties and in some of the *punctatum* cottons. B_2 is the key of all blackarm-resistance breeding in Upland types. On an Upland background, this gene confers grade '6' resistance, ranging to '7' under conditions of high humidity. Grade '6' is defined [15] as follows: 'Lesions rather more than 1 mm. across, brown, angular, wet at first but drying rapidly, not coalescing. Vein attack extends into surrounding tissues, making bands of brown about 2–2½ mm. wide.' Grade '7' is defined as follows: 'lesions up to barely 2 mm., brown, angular, remaining wet rather longer than "6". Lesions occasionally coalesce in small patches. Vein attack: wet bands about 3 mm. broad drying to brown.'

The value of B_2 in American Upland is best illustrated by a comparison of BAR 7/1 and SUS 7/2 (these are the blackarm-resistant and susceptible elements, respectively, selfed out of Uganda SP 84). In

1943–4 at Kadugli (Kordofan Province), where cotton is grown as a rain crop, BAR 7/1 gave 64 per cent. higher lint-yield than SUS 7/2 in a variety test, and this difference was attributed almost entirely to the effect of blackarm. In the same season, these two types were included in 5 variety tests in Equatoria Province. Taking the lint-yield of SUS 7/2 as 100 per cent. at each of these tests, percentage yields were: BAR 7/1 117 per cent. at Lomeiga, 121 per cent. at Odema, 109 per cent. at Kagelu, 109 per cent. at Meridi, and 98 per cent. at Ali Madreggi. The first two of these sites are on the east bank of the Nile; Kagelu is situated on the west bank approximately 100 miles west of Lomeiga, and the last two lie a further 100 miles to the west. In interpreting these results it should be borne in mind that 'conditions in Equatoria, particularly on the west bank of the Nile, do not favour a blackarm epidemic to the same extent as do conditions in Kordofan or in the Gezira during the rains' [20].

B_2 confers grade '7' resistance on *barbadense* cottons. The economic value of this degree of resistance is best seen from a comparison of X 1730 A (a Sudan 'Egyptian' type) and BAR 1730 L (X 1730 A to which B_2 has been transferred). In 1943–4 this comparison was made at 5 sites in the Gezira. Taking the lint-yield of X 1730 A as 100 per cent., these variety trials gave the following results for BAR 1730 L: 100 per cent. at Azrag, 102 per cent. at Abu Wafi, 109 per cent. at Medani, 111 per cent. at Barakat, and 108 per cent. at Hag Abdulla. The first two sites, Azrag and Abu Wafi, are in the Northern Gezira where rainfall is light and blackarm is rarely severe and in 1943–4 blackarm was negligible on these plots. Medani and Barakat are in the Central Gezira and Hag Abdulla lies to the south. Here rainfall is heavier and a moderate attack of blackarm is not uncommon and was, in fact, recorded in 1943–4. In the same season, at Barakat variety tests, NT 2/39 (a selection from Sakel) yielded 550 lb. of lint per acre as against 665 lb. from NT 2/41, its blackarm-resistant counterpart, carrying B_2.

The spinning-test figures from the blackarm-susceptible parent type, X 1730 A, as compared with its resistant (B_2) counterpart, BAR 1730 L are of interest, since they show that B_2 can be transferred to a *barbadense* type without adversely affecting lint. The figures given below are averages from 6 variety tests, 3 in 1944–5 and 3 in 1943–4:

	Standard hair wt.	*Count × strength*			*Highest standard count*
		80's	*100's*	*120's*	
X1730A . .	159·7	2309·2	2029·8	1763·9	87·2
BAR1730L . .	158·3	2300·4	2026·9	1763·2	85·5

Lint samples from the 1943–4 variety tests at Kadugli (Kordofan Province) and Meridi (Equatoria) were submitted to Shirley Institute for test. BAR 7/1 from Kadugli showed a 'highest standard count' of 45 as against 40 for SUS 7/2, its susceptible counterpart, and BAR 7/1 from Meridi showed an H.S.C. of 63 compared with 58 for SUS 7/2.

B_3. This is a strong, partially dominant factor originally obtained from a *punctatum* cotton. When transferred to a *barbadense* type, B_3 confers '8·1'–'7·1' resistance when heterozygous (B_3b_3) and '5·1'–'7·1' when homozygous (B_3B_3). Grade '8·1' is typified by angular lesions which, individually, are about 2 mm. across and are mid-brown when dry, often coalescent. Vein attack: wet bands about 3 mm. broad, drying to mid-brown but not drying as rapidly as lesions on B_2 leaves. Typically the homozygote is of grade '6·1', and this is similar in every way to '8·1' except that the individual lesions and the 'vein-bands' are smaller. Lesions on B_3B_3 leaves do not dry as rapidly as do those on B_2 leaves.

When transferred to an Upland type, B_3 produces a similar degree of resistance to that already described for *barbadense*. It is not possible, however, in Upland types, to distinguish with certainty between heterozygous (B_3b_3) plants and homozygous (b_3b_3) susceptibles.

The value of B_3, both in Upland and *barbadense* breeding, lies in its additive effect when used in conjunction with B_2.

B_2 and B_3 are located on the same chromosome with a crossover value of about 32 per cent. B_1 is independent of the other two resistance genes.

In districts where blackarm disease is unlikely to be severe, B_2 alone would confer adequate resistance on Upland or *barbadense*; where blackarm is likely to be severe B_2 and B_3 should be used together. It is only in *barbadense* types intended for those regions where blackarm is likely to be most severe that the utilization of all three genes would be necessary.

A Blackarm-resistance Survey of American Upland Cottons

A large number of blackarm-resistant cottons is available as raw material for the plant-breeder. Many of these are listed in Part II of 'The Genetics of Blackarm Resistance' [14], others will be found in a series of reports by the writer [19, 20, 22].

In 1945, varieties representative of the U.S. commercial crop were kindly supplied by the U.S. Department of Agriculture. These were tested and have been included in the table below, together with the resistance classification of the more important American Upland varieties examined to date.

1. *Resistant types pure-breeding for B_2*

513 (ex Punjab Early Strain).
MU8b.
U4 Nyasa 5.
Uganda Nos. B31; B181; SP102.
NT205/43 (ex Uganda SP20).
BAR7/1 (ex Uganda SP84).
Dharwar American N 5 (Small sample).
BAR11/2 (XA129 hybrid).
BAR12/1 (Uganda BP52 hybrid).
BAR10/2 (Deltapine hybrid).

2. *Fully susceptible types lacking B_2*

Delta Webber 6.
Webber Nos. 38, 49.2.
Willett's Red Leaf.
Kapas Purao.
Durango.
Columbia Nos. 40, 43, 44.
Wilds Nos. 1, 11, 16, 16SC.
Bolland Upland Nos. 29, 99, 105.
XA129.
Triumph Nos. 145.C.51.30; 143.J.4.119; 143.K.2.130.
Pump Scheme Strain.

Acala 111 (Rogers).
Acala (Shafter P–18–C).
Nucala.
Young's Acala.
Rowden Nos. B6[1]; 42a; 2088.
Mebane (Triumph).
Mebane.
Oklahoma Triumph 44.
Rhyne's Cook.
Clevewilt strain 7.
Coker 100 strain 6.
Deltapine[1] 14.
Express Nos. 6637, 11384.
Stoneville Nos. 2B (8275),[1] 2C (7303).
Uganda Nos. BP52, SG29.
SUS7/2 (ex Uganda SP84).
SUS12/2 (Uganda BP52 hybrid).
Dekhan 169.
Batyr 508.
Ak Dzhura.

3. *Types heterogeneous for B_2 resistance*

Uganda Nos. SP84, SP84R.
511 (ex Uganda SG85).
U4.4.2.
U4 Nyasa Nos. 4, 8, 9, 10.

4. *Synthesized types carrying B_3*

BAR13/1 (511 carrying B_2 and B_3).
BAR7/6 (Uganda SP84 carrying B_3 without B_2).

It is noteworthy that B_2 has, so far, been found only in cotton types belonging to the green-seeded small-bolled group of American Uplands (though by no means all the cottons in this group are resistant). This is in agreement with the suggestion [24] that the green-seeded cottons came from the more humid eastern portions of Central America and Mexico, whilst the big-bolled white-seeded cottons came from the interior, drier sections of Mexico. Selection pressure in favour of types carrying B_2 would clearly have been intense under the humid conditions in which the small-bolled types are thought to have originated. Blackarm-resistance would be of little selective value in the drier sections of Mexico—the home of the big-bolled types, and no big-bolled types carrying B_2 have as yet been found.

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BREEDING COTTON RESISTANT TO BLACKARM DISEASE

(*Bact. malvacearum*)

PART II: BREEDING METHODS

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WITH PLATE 4

Breeding for resistance.—Under natural conditions, in a season favourable to the spread of the disease, each plant in a plot of susceptible cotton will sooner or later be attacked. The attack will not, however, be initiated simultaneously in every plant, so that in comparing the lesions of two plants, either in quantity or quality, an unknown factor, age of lesion, vitiates clear judgement. Some plants will be infected at germination from the seed-coat, and the fuzz (primary infection); these, in a bad season, are often girdled and die. Others will be infected at intervals, the length of such intervals depending on various seasonal factors. Judging resistance on natural infection is further complicated by the fact that lesion-size is affected by the age of the plant-tissue and, especially in the case of leaves, by the climatic conditions (wind, humidity, temperature, cloudiness) under which the tissue developed. The growth of the disease organism is affected by temperature, and cool cloudy periods greatly increase the incubation period and slow down the rate of growth of lesions [20].[1] One cannot judge resistance with certainty as between individual plants when they have been subjected to such a variable infection as this. Complete evenness of infection is imperative and is best obtained by spraying the plants on a standardized basis with a suspension of *B. malvacearum*. Until the breeder has become experienced in handling the resistance genes B_2 and B_3 under his local conditions of climate and growth, he should sterilize his seed to protect his breeding-material against uneven infection. This prevents, or greatly reduces, primary infection and so avoids spreading the disease in a breeding-plot before spraying has been done. There are several proprietary mercuric dusts suitable for sterilizing blackarm-infected seed.

Preparation of inoculum and the method of spraying.—Knight and Clouston [13] described the method used for preparing inoculum and for infecting plants evenly with blackarm. Experience has shown, however, that perfectly even infection can be obtained by using an inoculum made by soaking 5 lb. of air-dried diseased leaves in 40 gals. of water, instead of the 10 lb. originally advocated. The infected leaves are soaked in water for 1 hour and then continuously crushed and stirred for a further hour; the suspension is then strained through sacking and used immediately. 'Solo-sprayers' are used for spraying and the jet is directed at the plant from ground-level upwards. Spraying is done twice a day for

[1] For this and other references up to no. 23 see end of Part I.

2 successive days, so that, on the present technique, each plant receives 4 sprayings with suspension, compared with the 6 previously advocated.

The following method is used to minimize differences between individuals doing the spraying and also time-of-day effects. The first spraying is carried out by working up the cotton ridges always in the one direction (and returning empty). Ridges on the left side of the plot are sprayed first, those on the right last. When the final ridge is sprayed the gang returns to the left side of the plot and the second treatment is given, the ridges being sprayed in the reverse direction this time. On the second day the process is repeated starting at the right side of the plot and working to the left (Plate 4). Spraying is done 6 weeks after sowing and, to avoid inter-plant differences due to age, it is best not to re-sow plots designed for blackarm-resistance breeding.

When spraying with inoculum is followed by a prolonged period of more or less continuously overcast, cool, damp weather (daily max. temps. about 75° F.), clear-cut ratios of resistant to susceptible phenotypes are not to be expected. In such conditions the incubation period of the disease is very prolonged and even the susceptible controls are unlikely to develop a satisfactory, even infection.

Ideal conditions for work on blackarm-resistance are given by heavy rainstorms followed by hot sunny periods.

Grading plants for blackarm-resistance.—Knight and Clouston [13] give details of a system of grading for blackarm-resistance on a scale in which '0' represents immunity and '12' the full susceptibility associated with Egyptian types (grade '11' is absent from this scale). This system is fully illustrated by Knight [15]. On this classification, susceptible American types would be of grade '10' and the usual resistance associated with B_2 would be about grade '6', in an Upland variety, and '7' in a *barbadense* type.

Where only B_2 is involved, it is unnecessary, in plant breeding, to use such a detailed method of grading. All that is required is classification of individual plants into 'resistant' or 'susceptible', since these two groups are easily recognized, there being no intermediate types. Controls should be used liberally in the breeding-plot until experience is gained of classifying plants and varieties under the local environmental conditions, after which they can be used more sparsely. Suitable control types are:

Resistant (B_2B_2) *type*	*Susceptible* (b_2b_2) *counterpart*
BAR7/1 (ex Uganda SP84).	SUS7/2 (ex Uganda SP84).
BAR11/2 (XA129 hybrid).	XA129 (ex Pump Scheme Strain).
BAR12/1 (Uganda BP52 hybrid).	SUS12/2 (Uganda BP52 hybrid).

Various other resistant and susceptible types exist, but the varieties listed above have been through the Sudan blackarm-resistance breeding plots and are known to be homozygous for resistance or susceptibility.

No amount of description, whether written or photographic, will give a plant-breeder the ability to select with confidence for blackarm-resistance. This capacity can be acquired far more easily by growing resistant and susceptible controls side-by-side, spraying them with blackarm inoculum and watching day by day the development of the disease on the leaves; it will soon be apparent that the difference between

B_2 and b_2 types is clear with no possibility of confusion. The reason for choosing leaf-symptoms as the criterion of resistance have been given elsewhere [13, 14, 26]; they are recapitulated and expanded here.

'Under the climatic conditions obtaining in the Sudan Gezira the leaf is of great importance in the blackarm problem: stem-infection frequently occurs via the petiole, and the bolls are infected, later in the season, through rain splash from diseased leaves and leaf debris. For this reason leaf-resistance was taken as the primary basis in selection work. The capacity of the bacterium for infecting the leaf-tissues and the quantity and quality of the damage done were the criteria adopted' [13].

It has been shown that there is a close correlation between leaf- and stem-resistance [13], so that although plants are not graded for stem-resistance, selection for leaf-resistance automatically brings about stem-resistance. 'Hansford [12], writing of blackarm in Uganda, attributes the major damage to stem-infection but states that this occurs in 99 per cent. of cases as the result of the extension of leaf-attack and that, without the latter, infection of the stem will not occur. Uganda appears to differ in this respect from the Sudan where leaf infection alone is capable of considerably reducing the yield. It matters little, however, for plant-breeding purposes, whether the crop loss is a direct or indirect sequel to leaf-infection, since control of the latter still remains the key to the problem' [14]. The results of yield trials previously quoted amply demonstrate the value of breeding work, based on leaf-resistance, in a climatic range covering the Gezira, Kordofan, and Equatoria. Briefly, the leaves have been found to be the simplest part of the plant to work with, and since the resistance conveyed by B_2 and B_3 is general to the whole plant their use is unexceptionable.

Selection for B_2-resistance in Upland types.—Some varieties of Upland cotton already contain a proportion of plants carrying B_2-resistance. In such cases it is a simple matter to select a number of plants showing resistance similar to that of the B_2B_2 controls. Progeny rows from these plants should be grown in an isolated area interspersed with controls. These progenies, each comprising a minimum of 25 plants, should be sprayed with inoculum and examined after 10–15 days. Some will be pure-breeding for resistance, having come from parents of B_2B_2 composition. Others will throw a ratio of 3 resistant plants to 1 susceptible, having come from B_2b_2 parents. The latter progenies should be pulled up, together with the controls, leaving only the B_2B_2 rows, which can then be bulked together as the new resistant strain of the original variety. A detailed example of this type of 'sorting' for blackarm-resistance is given by Knight [19] for the Uganda variety SP84R. For convenience this account is reproduced below:

'300 seeds of Uganda SP84R were imported through the kindness of Mr. H. R. Hosking of the Uganda Department of Agriculture. 200 of these were sown and from them 137 plants were raised and sprayed with Blackarm suspension. 79 Blackarm-resistant plants were present, the remaining 58 plants showing full (American) susceptibility. There were no intermediate types and the resistance of the resistant plants was exactly similar to that shown by controls of NT61—a Pump Scheme derivative to which B_2 has been transferred.'

'Forty-seven resistant plants were selfed and grown in progeny rows in 1941–2 winter, of these 14 proved to be homozygous for resistance and 33 were heterozygous. Thirty of these 33 families were examined in detail and they showed a total of 2,358 resistant to 692 fully susceptible plants against an expectation on a 3 : 1 basis of 2,287½ : 762½. The total X_2 for these figures (obtained by adding together the individual X_2 figure for each family) is 29·00, giving P = 0·5 approx., and proving that the figures obtained do not differ significantly from a monohybrid 3 : 1 ratio. Clearly the resistance of Uganda SP84R is due to a single factor, and since the degree of resistance is identical with that conferred by B_2 (the usual resistance factor in American types), there can be little doubt that this gene is B_2.'

'Seed from the 14 progeny rows of Uganda SP84R, mentioned above as being homozygous for B_2, will be used for sowing a 3¼ acre propagation area next season under the strain reference number BAR7/1. In addition, all fully susceptible plants in Uganda SP84R were selected for bulk-selfing and this seed will be used for sowing a 1-acre propagation area of the susceptible component of SP84R under the reference number SUS7/2.'

The bulk selection of the blackarm-resistant component of Uganda SP84R is fast becoming the sole commercial variety in the rain-areas of the Anglo-Egyptian Sudan.

Adding B_2 by Hybridization

(*a*) *American Upland varieties.*—Most American Upland varieties (especially those most popular in U.S.A. at present) do not carry B_2 at all, so that it is impossible to obtain resistance by straight selection. Indeed, if odd resistant plants are found in a pure-breeding susceptible type, they can safely be attributed to outcrossing. Selection of such outcrosses as a means of making the original variety resistant would obviously be undesirable.

Doubtless in certain of the susceptible types selection could, over a period of years, build up a complex of minor genes giving a weak degree of resistance. Such resistance would, however, be of little value and no amount of selection would, in the absence of a chance (and apparently very rare) mutation, lead to the inclusion of B_2 in a strain which did not previously possess it. Thus, in dealing with pure-breeding susceptible varieties, the breeder is forced to turn to hybridization in order to obtain any worth-while blackarm-resistance.

To many breeders hybridization and varietal change are almost synonymous. In breeding for blackarm-resistance, however, the objective is to transfer resistance to existing commercial types without altering their other varietal characteristics in any way. This, fortunately, is easily accomplished by backcrossing, because both B_2 and B_3 appear to be free from close linkages with other genes of economic importance.

Any of the resistant (B_2B_2) control types listed above would make a suitable donor parent in a scheme of backcrossing designed to transfer B_2 to a susceptible variety. The resistant and susceptible parents should be crossed in bulk (not single plants). Bulk-crossing is a means of preserving the genetic variability of the recurrent parent. The F_1 plants from this cross, being all of B_2b_2 composition, will be resistant and this resistant F_1 should be bulk backcrossed to the susceptible parent, using

the latter as the female. The progeny of this backcross, which should comprise at least 20 plants, will consist of half-and half-resistant (B_2b_2) and susceptible (b_2b_2) plants. The susceptible should be removed and the remainder backcrossed in bulk to the susceptible variety (backcross parent). This process should be continued backcross by backcross until variety tests of the type described elsewhere [25] show the resistant and susceptible components of the backcross progenies to be identical in spinning quality, yield, &c.

With most American varieties not more than 5 backcrosses would be required in transferring B_2 from any of the Upland control types listed. Where the susceptible backcross parent strain is of particularly long staple and high quality, 6 backcrosses might be required, whereas 4 (or even 3) would probably be adequate for the lower quality bread-and-butter cottons.

When the end-point is reached, all the resistant plants in the backcross progeny should be selfed and their seed bulked and sown as a single 'family'. This family would consist of 75 per cent. of resistant plants (25 per cent. B_2B_2 and 50 per cent. B_2b_2) and 25 per cent. susceptible (b_2b_2) plants. Progenies (each consisting of at least 25 plants) from all resistant plants should be sown in rows in an isolated area, sprayed with inoculum and those rows 'splitting' for resistance pulled up. The remaining rows then become the first propagation plot of the new resistant strain of the original susceptible commercial variety.

The account given above is very brief, but the subject of backcrossing in cotton breeding with particular reference to blackarm-resistance is discussed in greater detail elsewhere [25].

(*b*) '*Egyptian*' *varieties*.—The transference of the *hirsutum* gene B_2 to 'Egyptian' types confers on them a very useful degree of resistance; this factor is the 'key-gene' in all Egyptian breeding-work against blackarm. The following Egyptian strains, carrying B_2, have now been synthesized in the Sudan and these form suitable parent stocks for further transference within the *barbadense* group:

Resistant (B_2B_2) *type*	*Susceptible* (b_2b_2) *counterpart*
BAR4/5 (X1730 hybrid).	X1730A.
BAR5/5[1] (X1730 hybrid).	SUS5/4[1] (X1730 hybrid).
BAR2/10 (NT2 hybrid).	NT2/39.
BAR14/1 (Domains Sakel hybrid).	Domains Sakel.

In transferring B_2 from any of these resistant types to a normal (i.e. susceptible) variety of *barbadense*, no detailed grading for resistance such as that described by Knight and Clouston [13] would be necessary. The difference between the type of blackarm attack on a B_2B_2 *barbadense* and on a normal (b_2b_2) *barbadense* is sharp and beyond possibility of confusion under standardized conditions of infection. The breeding-plots should include a number of control rows of b_2b_2 and B_2B_2 type (the types listed above are suitable for this) and judgement of resistance versus susceptibility should be based solely on a comparison with these.

[1] X1730 types carrying the *G. arboreum* gene R_2^{RS} governing reddish flowers and leaves.

B_2 should be transferred from a resistant type to the local commercial variety by backcrossing, a suitable donor parent being chosen from those listed above. For transference to Sea Island or to Sakel strains, BAR14/1 would be the most suitable source of B_2, whereas BAR4/5 or BAR2/10 would be the best donors in transference work involving Egyptian 'Uppers'. The actual technique involved in the transference is identical with that used in American Upland breeding (pp. 164–5).

The role of B_3 in resistance-breeding.—In many areas B_2 alone confers adequate resistance on Upland types, but in districts subject to severe outbreaks of blackarm, B_2, though of great value, is not alone sufficient to nullify the effect of the disease. Fortunately the two factors B_2 and B_3 are additive in effect so that in breeding varieties for such districts it is possible to get a greater degree of resistance by including both factors. Of the two B_2 is distinctly the stronger[1] and it has the great advantage that it gives clear-cut ratios of resistant to susceptible plants in backcross progenies. There therefore is no point in using B_3 by itself in either *barbadense* or Upland breeding work. The value of B_3 lies in its additive effect when used in conjunction with B_2. B_3, though straightforward in *barbadense* transferences, is a difficult factor to use in Upland breeding because it does not give clear ratios.

There are two types of hybridization likely to be encountered in utilizing B_3: (1) adding B_2 and B_3 to a fully susceptible variety, and (2) adding B_3 to a variety already homozygous for B_2. The question of 'sorting' a variety heterogeneous for B_3 has not arisen because B_3 has never yet been found naturally occurring in either Upland or 'Egyptian' types.

1. *Adding B_2 and B_3 to a Fully Susceptible Variety*

(*a*) *American Upland varieties.*—In the first case, that of adding both B_2 and B_3 to a susceptible type, the two factors should be handled separately as parallel transferences and combined after backcrossing is completed. Should the local commercial variety not be pure for susceptibility, but heterogeneous for B_2, then, during the process of 'sorting' for resistance, the susceptible (b_2b_2) component should be selfed out for use as backcross parent in the B_3 transference.

The factor B_3 shows only partial dominance and the F_1 of a cross between a B_3B_3 variety and a susceptible Upland has only weak resistance. Individual plants in this F_1 of B_3b_3 composition show symptoms ranging from recognizable resistance down to the grade of blackarm found on the less heavily attacked variants in the susceptible control. In working with a gene whose heterozygote is difficult to distinguish from the homozygous recessive, it is advisable to run 4 or 5 lines of backcrossing in order to guard against accidental loss of the gene (this practice also preserves the genetic variability of the backcross parent variety). The F_1 should therefore be divided into 4 groups of plants and each group

[1] This is contrary to an earlier statement [15] in which B_3 when homozygous was claimed to be stronger than B_2; using the late Sakel backcross material, however, and comparing B_2B_2 Sakel with B_3B_3 Sakel over several seasons, the latter does show itself to be 'weaker' than the former.

should be separately 'bulk-backcrossed' to the commercial parent. In all subsequent backcrossing these 4 lines should be kept separate, the homozygous end-products from them being bulked. As a control for use in selecting resistant (B_3b_3) plants in backcross progenies, an F_1 of B_3B_3 Upland × b_3b_3 Upland should be sown each year, together with controls of the susceptible parent.

These backcross progenies will not throw straightforward 1 : 1 ratios of resistant to susceptible types and the easiest way of dealing with them is to select, in each progeny, a group of 10–20 plants showing maximal resistance for further bulk-backcrossing. Typical distributions obtained in backcrossing B_3B_3 Upland to b_3b_3 Upland are given below:

	Grade of blackarm-resistance			
	'7'	'8'	'9'	'10'
Control XA129 (b_3b_3)	..	1	8	25
Backcross progenies	..	20	80	30
Control BP52 (b_3b_3)	..	..	10	15
Backcross progenies	52	18	20	76
Control SUS7/2 (b_3b_3)	..	..	16	22
Backcross progenies	2	28	59	42

In the XA129 backcross progenies above, the grade '8' plants were selected for further bulk-backcrossing, it being assumed that they would mostly be of B_3b_3 composition. In the BP52 backcrosses grade '7' plants were selected and in the SUS7/2 backcrosses grade '7'–'8' plants were chosen.

When backcrossing is complete all plants having maximal resistance (B_3b_3) in each of the four lines should be selfed. The product of the resistant plants in each progeny is then sown as a separate bulk giving 4 backcross F_2s. These 4 F_2 bulks should be sprayed with inoculum and examined for resistance, plants with maximal resistance are presumed to be of B_3B_3 composition since B_3 is only partially dominant. These resistant plants should be grown in progeny rows (each containing at least 25–30 plants) in an isolated place and any rows found to be splitting for resistance should be removed. The remainder would then be bulked as a homozygous B_3 strain.

Examples, from actual transferences, of the type of distribution found on selfing B_3b_3 plants in Upland backcross progenies are given below:

	Grade of blackarm-resistance					
	'5'	'6'	'7'	'8'	'9'	'10'
Control XA129 (b_3b_3)	..	..	..	..	46	
Backcross F_2 progenies	..	34	101	208	82	96
Control SUS7/2 (b_3b_3)	..	..	..	4	26	12
Backcross F_2 progenies	166	115	87	85	103	9

In the first of these progenies the grade '6' plants were selected for individual selfing. In the second group of progenies high winds hardened

the leaves giving them an added resistance; here grade '5' plants were selected for selfing. In growing the progeny rows from each group of resistant plants all 4 lines of backcrossing were again brought together so that homozygous B_3 rows from all 4 entered into the final B_3 strain. Comparable distributions to these are to be expected on selfing out and they should be treated similarly.

The production of a strain homozygous for B_3 completes the first stage in the process of synthesizing a variety carrying both B_2 and B_3.

(*b*) *'Egyptian' varieties.*—Experience has shown that it is much easier to transfer resistance factors separately, integrating the final multifactorial strain at the end of the transference. The transfer of B_3 to the local susceptible commercial type should therefore be carried out as a separate piece of breeding from the B_2 transference, the 2 lines of work being 'run' in parallel.

Several 'Egyptian' strains carrying B_3 have been synthesized and these are listed below; they should provide material for controls and, also, suitable parent stocks for further transferences.

Resistant (B_3B_3) *type*	*Susceptible* (b_3b_3) *counterpart*
BAR4/9 (X1730 hybrid).	X1730A.
BAR2/22 (NT2 hybrid).	NT2/39.
BAR14/2 (Domains Sakel hybrid).	Domains Sakel.

The actual transference of B_3 from one of the resistant types listed above to a susceptible type should follow the standard lines used in working with B_2. B_3 lacks full dominance and for this reason the controls used as standards in the backcross progenies should be B_3b_3 (i.e. the F_1) and the commercial susceptible backcross parent variety (b_3b_3). The difference between the heterozygotes (B_3b_3) and the fully susceptible plants (b_3b_3) in backcross progenies is not as outstanding as were the differences found in working with the gene B_2, but a careful examination of B_3b_3 and b_3b_3 controls sown side-by-side and subjected to standardized spraying with inoculum should enable the breeder to recognize these two types with certainty.

On selfing the B_3b_3 plants in the final backcross progenies a ratio of 25 per cent. B_3B_3 : 50 per cent. B_3b_3 : 25 per cent. b_3b_3 will be obtained. B_3B_3 controls sown against B_3b_3 and b_3b_3 controls should enable the breeder to choose the plants for selfing which are most likely to be homozygous for resistance (i.e. the plants with maximal resistance). After experience in judging resistance has been gained, progenies of these selected plants should all be pure for resistance, any progenies which throw a 3 : 1 ratio of resistant to susceptible plants can be pulled up. The remaining progenies are bulked as the resistant strain.

Integration of 'Egyptian' or Upland strains carrying both B_2 and B_3.—In building up a B_2B_3 type, it is easier to transfer B_2 and B_3 separately to the susceptible stock, and combine them when the transferences are complete, than to transfer B_3 to an existing B_2B_2 variety by repeated backcrossing. By transferring the genes separately, the more difficult task of selecting for maximal resistance within a resistant population is relegated to a single operation at the end of the transferences. Repeated

backcrossing of B_3 to a B_2B_2 stock would entail accurate grading of every backcross progeny as well as of the final stage.

The synthesis of varieties of B_2B_2 and B_3B_3 composition has already been discussed. The first step in integrating a strain homozygous for both factors is to bulk-cross the B_2B_2 type with the B_3B_3 type. This will produce an F_1 of $B_2b_2B_3b_3$ composition. These F_1 plants should be bulk-selfed and the progeny sown as a single 'family' interspersed with controls[1] of B_2B_2, B_3B_3, $B_2B_2B_3B_3$, and $b_2b_2b_3b_3$ (susceptible) types. This family will comprise the following genotypes in approximately the proportions shown below. These proportions differ from the classical 15 : 1 dihybrid ratio because the 2 genes are linked and are in the repulsion phase in the 'family' in question. Hence, in F_2, the proportion of resistants to susceptibles will be greater than the 15 : 1 ratio expected with free assortment. With the 32 per cent. crossing over observed with these genes the expectation is approximately 35 resistant plants to 1 susceptible ($b_2b_2b_3b_3$).

(*a*)	1 $B_2B_2B_3B_3$	(*e*)	10 $B_2b_2B_3b_3$	} 35
(*b*)	4 $B_2B_2B_3b_3$	(*f*)	4 $B_2b_2b_3b_3$	
(*c*)	4 $B_2B_2b_3b_3$	(*g*)	4 $b_2b_2B_3B_3$	
(*d*)	4 $B_2b_2B_3B_3$	(*h*)	4 $b_2b_2B_3b_3$	
	(*i*) 1 $b_2b_2b_3b_3$			1

In this family, plants of type (*i*), being fully susceptible, can be 'spotted' at once and removed. Reference to the B_3B_3 controls will enable the breeder to recognize the characteristic B_3-type of resistance (especially in *barbadense* varieties) and plants belonging to genotypes (*g*) and (*h*) will accordingly be pulled up. By careful comparison with the B_2B_2 controls it should be possible to recognize and remove types (*c*) and (*f*), leaving genotypes (*a*), (*b*), (*d*), and (*e*) to be dealt with. These genotypes comprise the plants showing maximal resistance to blackarm.

All these plants should be separately selfed and sown in progeny rows interspersed with controls of B_2B_2, B_3B_3, and $b_2b_2b_3b_3$ strains. Some of these progeny rows (those from (*e*) plus those from any plants of (*f*) genotype not previously removed) will contain a proportion of fully susceptible plants and such rows can be pulled up. Other rows (those from (*d*) above) will contain a proportion of plants with resistance similar to that of the B_3B_3 controls: these rows should all be removed. Still other rows (those from (*b*) above) will contain 25 per cent. of plants with resistance similar to that of the B_2B_2 controls: these rows, also, should be pulled up. This will leave only rows in which *every plant* shows greater resistance than either of the resistant controls. These progenies should all be of $B_2B_2B_3B_3$ type, and they together comprise the newly integrated extra-resistant strain.

Should the plant-breeder find difficulty in working with B_2 and B_3 together by reason of inexperience in assessing black-arm resistance, the final steps shown above can be simplified. In this case the B_2B_2 and B_3B_3 strains are crossed and the F_1 is backcrossed to the B_3B_3 type. The progeny (minimum size 80 plants) of this cross will contain the following

[1] Suitable control types of $B_2B_2B_3B_3$ composition are BAR13/1 in Uplands, and BAR4/11 and BAR2/27 in 'Egyptians'.

types of plants in proportions determined by the rate of crossing-over between B_2 and B_3:

(*a*) $B_2b_2B_3B_3$, (*b*) $B_2b_2B_3b_3$, (*c*) $b_2b_2B_3B_3$, (*d*) $b_2b_2B_3b_3$.

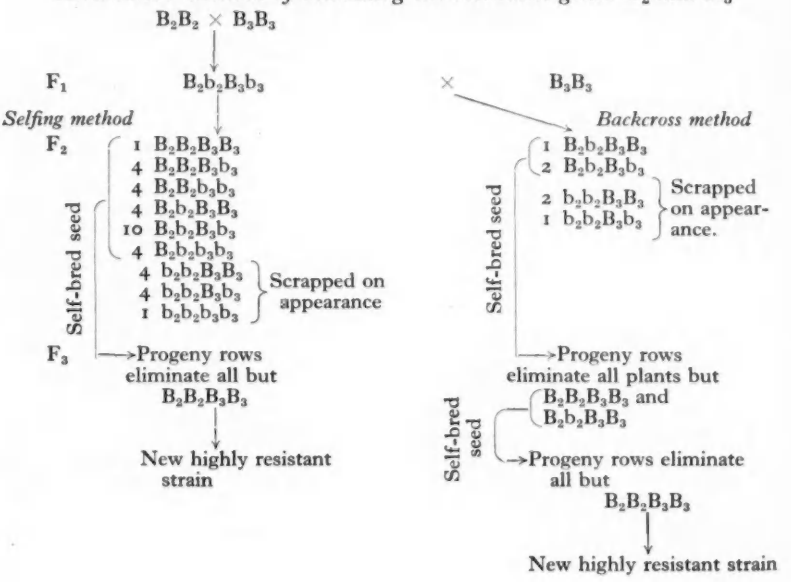
Types (*a*) and (*b*) will both show strong resistance, types (*c*) and (*d*) will be markedly less resistant and can be pulled up. The remaining plants (*a* and *b*) should be selfed and grown in progeny rows, each row containing at least 100 plants. One half of these progeny rows (those from *b* above) will throw a proportion of fully susceptible plants; such rows can be readily recognized and removed. The remaining rows will all be from plants of $B_2b_2B_3B_3$ composition and they will contain the following plant-types in the proportions indicated:

(*e*) 25 per cent. $B_2B_2B_3B_3$, (*f*) 50 per cent. $B_2b_2B_3B_3$, (*g*) 25 per cent. $b_2b_2B_3B_3$.

Of these, type (*g*) will show up clearly as being much less resistant than (*e*) and (*f*). Type (*g*) will therefore be pulled up leaving only the markedly resistant plants (*e* and *f*). These strongly resistant plants should be selfed and grown in progeny rows: 1 in every 3 of them will be pure breeding for strong resistance being derived from (*e*) above, the others will throw a 3 : 1 ratio similar to that shown above ($e+f : g$). Such splitting progenies can be removed leaving only those of $B_2B_2B_3B_3$ composition. These latter should be bulked as the new extra-resistant strain.

These alternative methods of combining B_2 and B_3 in a single strain are illustrated below. B_2 and B_3 are located on the same chromosome, and when a B_2B_2 type is crossed with a B_3B_3 type the 2 genes are in the 'repulsion' phase in the F_1.

Alternative methods of combining the resistance genes B_2 and B_3



2. Adding B_3 to an Upland Variety already Homozygous for B_2

The addition of B_3 to a type already homozygous for B_2 is likely to be necessary only in American Upland breeding, since the susceptible counterpart would be available in 'Egyptian' breeding. The process is carried out by backcrossing. BAR7/6 or a similar synthesized B_3 type is crossed with the strain carrying B_2 and repeatedly backcrossed to it. When backcrossing has gone far enough the homozygous $B_2B_2B_3B_3$ type is selfed out and propagated.

This whole process calls for accurate grading for blackarm-resistance of all the individual plants in each backcross progeny. It is impossible to classify these progenies into the 2 groups 'resistant' ($B_2B_2b_3b_3$) and 'very resistant' ($B_2B_2B_3b_3$), because these groups overlap, as will be seen from an examination of the following distributions obtained in backcrossing B_3 to a B_2B_2 type:

	Grade of blackarm-resistance			
	'4'	'5'	'6'	'7'
Control 511D (B_2B_2) . .	3	102	40	..
Backcross progenies . .	68	246	57	..

In these progenies all plants showing greater susceptibility than grade '4' were pulled up and the grade '4' plants (presumed to be $B_2B_2B_3b_3$) were then re-examined and any showing rather more severe blackarm than 'good' grade '4' were culled. The remaining plants were used for bulk-backcrossing to the B_2B_2 type, each progeny being kept separate.

When varietal tests show that backcrossing has gone far enough plants of maximal resistance are selected for individual selfing.

The kind of distributions likely to be found in the F_2 progenies of the final backcross can be seen from the following example.

Blackarm Grading of Sample Families in the F_2 of the 4th Backcross of B_3B_3 punctatum to B_2B_2 511D

	'3'	'4'	'5'	'6'	'7'	*Remarks*
Totals of controls (511D–B_2B_2) .	..	7	114	69	18	
Family 375/44	..	2	21	8	..	Scrap; B_2 only
,, 376/44	..	46	41	1	..	
,, 377/44	3	31	49	4	..	
,, 378/44	..	9	42	7	..	Doubtful
,, 379/44	..	..	16	7	..	Scrap; B_2 only
,, 380/44	..	..	15	17	2	Scrap; B_2 only
,, 381/44	..	..	5	10	7	Scrap; B_2 only
,, 382/44	..	19	64	3	..	

In the above families, plants of 'good' grade '4' were selected in 376/44 and 382/44 and plants of grade '3' ranging to 'good' grade '4' (i.e. '4–') were selected in family 377. These selections were presumed to be mainly of $B_2B_2B_3B_3$ and $B_2B_2B_3b_3$ composition. These plants were all selfed and sown in progeny rows against controls of 511D (B_2B_2).

Any rows containing plants with blackarm symptoms similar to the control type were eliminated and the remaining rows were bulked as the new $B_2B_2B_3B_3$ strain of 511D.

Role of B_1 in 'Egyptian' resistance-breeding.—B_1 is a weak factor. Used in conjunction with B_2 it has a slight additive effect, but since B_2 and B_3 together form a stronger combination than do B_1 and B_2 it is clearly better, where a 2-factor strain is required, to use B_2B_3 rather than B_1B_2. The value of B_1 lies in its marked additive effect when it is used in conjunction with B_3; the addition of B_1 to an 'Egyptian' carrying B_2 and B_3 confers a degree of resistance which approaches immunity.

Suitable strains for use as parents and controls in working with B_1 would be:

Resistant (B_1B_1) type	*Susceptible (b_1b_1) counterpart*
BAR4/2 (X1730 hybrid).	X1730A.
BAR2/11 (NT2 hybrid).	NT2/39.
BAR14/3 (Domains Sakel hybrid).	Domains Sakel.

The factor B_1 is fully dominant and its transference to a susceptible stock follows identical lines to those used in the B_2 transference already discussed.

Integration of 'Egyptian' strains carrying all three genes, B_1, B_2, B_3.—In building-up a $B_1B_2B_3$ strain the first steps are the making of 2 types, one carrying B_1 and B_3 and the other carrying B_1 and B_2.

A homozygous B_1 strain is crossed with its homozygous B_3 counterpart giving F_1 plants of $B_1b_1B_3b_3$ composition. These should be bulked-selfed and the seed sown as a 'family' interspersed with B_1B_1, B_3B_3, and $b_1b_1b_3b_3$ controls. In F_2 the following types will appear in the proportions indicated:

(*a*) 1 $B_1B_1B_3B_3$
(*b*) 2 $B_1b_1B_3B_3$
(*c*) 1 $b_1b_1B_3B_3$
(*d*) 2 $B_1B_1B_3b_3$
(*e*) 4 $B_1b_1B_3b_3$
(*f*) 2 $b_1b_1B_3b_3$
(*g*) 1 $B_1B_1b_3b_3$
(*h*) 2 $B_1b_1b_3b_3$
(*i*) 1 $b_1b_1b_3b_3$

Plants of genotype (*i*) will be fully susceptible and can be pulled up, whilst (*g*) and (*h*) will show the weak resistance typical of B_1 and can also be removed. Plants belonging to (*c*) and (*f*) will either be similar to the B_3B_3 controls or show weaker resistance; as the B_3-type of resistance is of rather characteristic appearance these types should, with practice, be recognizable and can be removed. The only plants left after this should be those showing greater resistance than either resistant control (*a*, *b*, *d*, and *e*). Progeny rows from these should be grown, interspersed with B_1, B_3, and susceptible controls, and sprayed with the disease. Progenies from (*e*) can be recognized, and discarded, because they will contain a proportion of fully susceptible plants. Progenies from (*d*) are almost equally easy to recognize, since they will have a proportion of weakly resistant plants similar to the B_1 control. Progenies from (*b*) will have a proportion of plants of similar resistance to the B_3 control. This leaves only families of (*a*) type, and these together make the $B_1B_1B_3B_3$ strain.

This method of combining B_1 and B_3 requires considerable experience in grading for blackarm-resistance. The 'backcross method', noted as a possible way of combining B_2 and B_3, is of value here as providing a relatively simple, though laborious, method of producing a $B_1B_1B_3B_3$ variety. On this system B_1B_1 and B_3B_3 strains are crossed and the F_1 ($B_1b_1B_3b_3$) is bulk-backcrossed to the B_1B_1 variety to yield a progeny consisting of equal proportions of the following types:

(*j*) $B_1B_1B_3b_3$ } markedly resistant types. (*k*) $B_1b_1B_3b_3$ }

(*l*) $B_1B_1b_3b_3$ } weakly resistant (grade '10.1') types. (*m*) $B_1b_1b_3b_3$ }

Weakly resistant plants (*l* and *m*, above) are pulled up leaving the markedly resistant types (*j*) and (*k*). Progeny rows from type (*k*) throw a 15 : 1 ratio of resistant to fully susceptible plants and such rows can be pulled up on inspection. Progeny rows from (*j*) will contain no fully susceptible plants but will show a ratio of 3 markedly resistant plants to 1 weakly resistant plant. This ratio will be made up as follows:

(*n*) 25 per cent. $B_1B_1B_3B_3$ } markedly resistant types. (*o*) 50 per cent. $B_1B_1B_3B_3$ }

(*p*) 25 per cent. $B_1B_1b_3b_3$ { weakly resistant types.

In such progenies, weakly resistant plants (*p*) are pulled up leaving the markedly resistant plants belonging to groups (*n*) and (*o*). These plants should be selfed individually. Progeny rows from these of type (*n*) will breed true for marked resistance, those from type (*o*) will contain a proportion of weakly resistant plants. Such rows should be scrapped, leaving those derived from (*n*) to form the new homozygous strain of B_1B_3 composition.

The second step is the combining of B_1 and B_2. This is done by crossing a B_1B_1 strain with a B_2B_2 strain and backcrossing to the B_1B_1 parent. The progeny of this cross will consist of equal proportions of $B_1B_1B_2b_2$, $B_1b_1B_2b_2$, $B_1B_1b_2b_2$, and $B_1b_1b_2b_2$ plants. Those belonging to the last two genotypes are easily recognized, since they will show only slight resistance. Such plants are removed, leaving only (*a*) $B_1B_1B_2b_2$ and (*b*) $B_1b_1B_2b_2$ types. These should be selfed and sown in progeny rows. Plants from type (*b*) will throw a proportion of fully susceptible plants; such progenies are pulled up. Progenies from type (*a*) plants will contain 75 per cent. of very resistant plants and 25 per cent. of plants showing weak resistance. The latter are removed and the very resistant plants are selfed individually and carried forward to progeny rows. All rows containing a proportion of weakly resistant plants should be uprooted and the remaining rows can be then bulked as a homozygous $B_1B_1B_2B_2$ strain.

The third stage in the synthesis of a type homozygous for B_1, B_2, and B_3 is to cross the $B_1B_1B_3B_3$ strain with the $B_1B_1B_2B_2$ strain, backcrossing the F_1 to the former. This will give a progeny made up of the following types in the proportions 1 : 2 : 2 : 1:

(*q*) $B_1B_1B_2b_2B_3B_3$ } Almost immune. (*r*) $B_1B_1B_2b_2B_3b_3$ }

(*s*) $B_1B_1b_2b_2B_3B_3$ } Grade '4'–'5' resistance. (*t*) $B_1B_1b_2b_2B_3b_3$ }

In this progeny, types (*s*) and (*t*) can be recognized as being definitely less resistant than types (*q*) and (*r*). Accordingly, plants showing maximal resistance (*q* and *r*) are selfed and carried forward to progeny

rows. Plants of type (*r*) will throw a proportion of weakly-resistant types in their progeny and such progenies are eliminated. Plants of type (*q*) will yield progenies having the following ratio:

(*u*) 25 per cent. $B_1B_1B_2B_2B_3B_3$
(*v*) 50 per cent. $B_1B_1B_2b_2B_3B_3$
} Almost immune.

(*w*) 25 per cent. $B_1B_1b_2b_2B_3B_3$ } Grade '4'–'5' resistance.

In these progenies plants of type (*w*) will be scrapped on appearance leaving types (*u*) and (*v*). Progeny rows from these will eliminate (*v*) since these will throw a proportion of grade '4'–'5' plants. Thus only rows of $B_1B_1B_2B_2B_3B_3$ composition will be left and these comprise the new near-immune strain.

Summary of Parts I and II

The only resistance to blackarm disease (*B. malvacearum*) of any importance found in American Upland types is dependent on a single fully dominant gene, B_2. Sometimes a weak gene, B_1, may also be present. Some varieties of *G. hirsutum* var. *punctatum* carry a second partially dominant gene, B_3. B_2 and B_3 are linked, having a 32 per cent. crossover value, and are additive in effect.

A resistance classification is given on a genetic basis of a number of Upland strains and details are given of a method of obtaining even infection on which classification for resistance is based.

Only one blackarm-resistant pure *G. barbadense* type has so far been found, viz. Grenadines White Pollen, and no genetical analysis of this has yet been made.

The genes B_1, B_2, and B_3 have all been transferred to Sudan varieties of *G. barbadense*. In this work, B_2 is the most important gene followed closely by B_3; B_1 is only of minor importance. Breeding methods are described for transferring these genes from resistant to susceptible varieties.

The following breeding methods are described in detail:

1. Sorting a strain which carries a proportion of B_2 plants so as to make it pure-breeding for resistance.
2. Transferring B_2 to a fully susceptible strain.
3. Transferring B_1, B_2, and B_3 individually to a fully susceptible strain.
4. Adding B_3 to a strain which already carries B_2.
5. Integrating 'Egyptian' strains homozygous for B_1, B_2, and B_3.

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(References 1–23 are to be found at the end of Part I.)

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Spraying cotton plants with blackarm inoculum

THE IMPROVEMENT OF SOIL FERTILITY

PART III: AGRICULTURE, FOOD, AND HEALTH

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(*Imperial Chemical Industries: Central Agricultural Control*)

IN the previous papers the discussion has been chiefly in terms of crop yields: of maintaining and increasing total crop production through improving soil fertility. The emphasis has been on 'quantity', although the importance of 'quality' has not been forgotten. The agricultural scientist is constantly aware that increasing crop production is not an end in itself, but only a means to a further end: that of more and better human food. No one can consider the problems of nutrition without thinking about the quality as well as the quantity of the food ingested. More must be said about this aspect of agriculture—food production—whose world-wide importance has now been recognized by the setting up of the Food and Agriculture Organization of the United Nations [3, 4]. Agriculture undoubtedly produces many industrially useful crops, and it will continue to do so; but its first and most important function is to supply food for men and animals.

Quantity and Quality in Agricultural Products

As was remarked above, the emphasis so far has been on quantity rather than quality, because under ordinary farming conditions the quality of products is usually at least adequate, and both for food supply and for industry the first requirement is to produce sufficient amounts of what is needed. If we are sure of having enough, then we can give more attention to its quality. When we consider hard realities as they exist in Asia, this is very evident: a shortage in quantity of food means famine, however good the quality might be of what food was available. And in general, people cannot live, grow, work, and remain healthy and energetic, on under 2,000 calories of food per day, however plentiful the supply of vitamins and other quality factors might be.

Quality in agricultural products is difficult to define: it may involve different attributes for different purposes; none the less an immense amount of work on quality factors has been carried out in recent years by investigators in agriculture and nutrition, and much is already known. One matter of paramount importance has always to be borne in mind: whilst we should do our best to improve the quality of crops and food supplies, we must be sure that the total quantity produced is not diminished thereby.

A. Howard and his followers [17, 18], who wish us to revert from the use of inorganic fertilizers to organic manures exclusively, have said much about quality, often ignoring the modern scientific work that has been done on the problem; and also ignoring the aspect that is stressed in the last sentence. Already the world is scarcely able to support its present population—indeed, a food crisis faces humanity as these words are written—and enough food can be produced only by supplementing the

local organic manures with inorganics. We cannot hope to feed the larger populations of the future except by making increased use of inorganic fertilizers. If, as Howard demands, we were to cease using these fertilizers, crop production would fall towards medieval levels, and world-wide famine would inevitably follow.

Granting this, the fact still remains that better quality is desirable in the diet of most people. The greater part of the world's population is suffering from malnutrition, and much of it from under-nutrition. Incidentally, the worst nutrition is found, like the highest death-rates and disease incidence, in the countries that make least use of inorganic fertilizers; in such countries as India, China, and the eastern European and South American states.

The factors that make up quality in foodstuffs are by now well understood scientifically [61, 62, 63]: in addition to balanced total quantities of carbohydrates, fats, and proteins, there should be sufficient animal protein to supply certain essential amino-acids; sufficient mineral salts, in the correct proportions; and sufficient vitamins. These last are best secured in the so-called 'protective foods': milk and milk products, other animal fats, eggs, grain germ and yeast, fruits and vegetables or their juices.

It is the general experience that if an ample and varied or mixed diet is taken these protective factors will, as it were, look after themselves. Thus the first essential of adequate nutrition is that there should be enough of the right kinds of food, and if this is attended to it is relatively less important where the foods come from or how they were manured. One value of mixed-farming systems is that they contribute to the supply of an adequate diet in this sense.

Much scientific study has already been made of the relation between the climate, the kind of soil, the variety, and the manuring of the crop on the one hand, and the quality of the produce on the other, including its nutritive value for animals and humans [64]. The broad upshot of the investigations is that almost all the other factors mentioned have more effect on quality than does manuring—whether with organic manures or inorganic fertilizers.

Humid climates and leached soils tend to give crops low in minerals, and hence of poor nutritive quality in this respect. Indeed, in a broad way, we can say that low-rainfall, even semi-arid, areas, which produce soils and vegetation rich in minerals, tend to give larger and relatively healthier livestock and human beings, whereas high-rainfall areas, with leached soils, giving vegetation poor in minerals, produce smaller and less healthy live stock and men. There are, of course, many complicating factors, including, with man, the kinds of food eaten and the extent to which the diet is supplemented by materials imported from elsewhere: yet the broad relationship, applying especially to live stock but sometimes also to men, may be seen to hold in India, in China, in the U.S.A., and elsewhere.

With leached soils, suitable manuring, including the use of lime and phosphates, may enrich the crops in the deficient minerals and hence improve their nutritive value [65, 66]. Mineralized salt-licks, and direct administration of phosphates to live stock, are valuable also. There are

some soils which are acutely deficient, naturally, in certain trace elements required for animal nutrition, such as cobalt or copper. With these, as has been found particularly in Australia and New Zealand, a small supplement of the missing element in fertilizer treatments has an almost miraculous effect on the health of the live stock [31, 67]; large amounts of cobaltized superphosphate are now used for this purpose.

With regard to vitamins, it must be borne in mind that most plants themselves synthesize the vitamins required for animal and human nutrition, quite apart from anything they may perhaps take up from the soil. In addition, animals such as ruminants take up certain vitamins at low concentrations in the vegetation they eat, and concentrate them in their milk or fat, which then contains sufficient for human nutrition. Thus there is no absolute need to use organic manures as a source of vitamins in food, even if in fact it were possible. Some experimenters [68] claim to have obtained better animal nutrition from grain grown with organic manures than with inorganic fertilizers, but others [69] have found that a well-balanced dressing of inorganic fertilizers gave grain at least as rich in vitamin as that receiving organic manure.

Apart from extreme cases of the unbalanced use of fertilizers, well-nourished plants give products about equally rich in vitamins, whether their nourishment comes from the soil, from organic manures, or from inorganic nutrients. There is some tendency for any factor which markedly increases vegetative growth—including abundant water and nitrogen supply—to dilute the concentration of carbohydrates and of vitamin C in the plant [70], but the overall increase in yield in such cases is more than sufficient to offset this effect. In general, varietal or soil differences cause much greater differences in the quality and vitamin-content of crops than does any normal manuring [71].

Thus there is no evidence that if inorganic fertilizers are wisely used as a supplement to local organic manures they appreciably lower the quality of the crop; on the contrary, where mineral deficiencies are present they may improve it. We may proceed with a clear conscience to extend the methods of modern intensive agriculture, as far as the question of quality of food is concerned.

Manuring, health, and disease.—So much has been said by A. Howard and his followers on this subject also that it must be referred to when one is considering the use of manures and fertilizers to increase food production. Howard appears to take the view that most of the ills of humanity are due to the use of inorganic fertilizers; but humanity had plenty of illness and disease before these were invented, and on the whole illness and death-rates have been decreasing, not increasing, during the past century. Most of Howard's arguments and evidence are of a *post hoc ergo propter hoc* nature, and they refer to such a complexity of changing factors that the possible influence of organic or inorganic manuring cannot be disentangled from other causes. Thus the case against inorganic fertilizers as a cause of disease is in no manner proved; and in any event the argument breaks down when the inorganics are employed as a supplement to local organic manures, in the manner usual in modern intensive agriculture.

In this matter of manuring and disease it is important to keep a sense of proportion. Whilst plant, animal, and human diseases occur everywhere in the world, they are more serious and widespread in some countries than in others. If we find that the countries with worst disease conditions are among those which use least inorganic fertilizers, we may at least conclude that inorganic fertilizers are not a major factor in disease causation.

With regard to plant and animal diseases, India, which uses practically no inorganic fertilizer, is over-run with them; and China, which uses much organic manure with negligible amounts of inorganics, has at least as much plant and animal disease as the U.S.A. or Great Britain. As Garrett [72] and Large [73] have shown, some plant-disease organisms are encouraged by both organic manures and inorganic fertilizers; others may be discouraged by one or other or both. The relationships are far too complex for a simple generalization. Some organic manures, consisting of plant residues, may actually transmit diseases and pests to the next crop.

As for human health, the highest death-rates and the worst disease conditions in the world are those of countries like China and India, which use little or no inorganic fertilizer; the countries using most inorganic fertilizers per head of population (New Zealand, Denmark, the Netherlands, and Germany) were before the war among the healthiest nations in the world, with the lowest death-rates and infantile-mortality rates [74]. In fact, other factors, such as climate, general standard of living, medical and health services, and over-all nutrition are far more important in this matter than the methods of manuring crops [75, 76]. Food shortages inevitably aggravate disease [77]. In so far as inorganic fertilizers make possible the production of more food, and especially of more protective foods, they can do only good. When all the world has sufficient to eat, and when the general level of health has been raised to that in Holland or New Zealand, it will be time enough for concern about whether some small further improvement is possible through varying the type of manuring used.

Conclusions

These papers have examined the chief factors in soil-fertility improvement, under different environments, with a view to increasing crop and food production in the future. The writer is not blind to the wider issues of agricultural policy, including the relations of different systems of agriculture to the social structure, and the question of what forms of land-utilization are most likely to offer health, a good life, and a high standard of living to the community, but there is no space to consider such implications here. Many of them are determined by political or other events outside the direct field of action of the agricultural scientist. At least it can be said that a society cannot hope to survive for long, at a high standard of living, if it does not maintain and improve the fertility of the soils it farms. Colonization and resettlement schemes in the post-war era also are likely to fail if they do not consider the fertility of their soils.

It was shown in the first paper [1] that the system which has most improved soil fertility, and which maintains it at its highest level, is that

of modern intensive agriculture. This makes full use of both organic manures and inorganic fertilizers, as well as other scientific and technical improvements. It usually involves either mixed farming or alternate husbandry, and thus—by providing the animal products as well as the grains and vegetables needed for a full, mixed diet—it contributes towards the best in human nutrition and health. It is capable also of providing a high standard of living for those on the land.

The problem chiefly discussed in the earlier parts of the present paper is the extent to which the methods of modern, intensive agriculture can be applied in different climates. For details, reference must be made to Part II: here, only general conclusions can be outlined.

Broadly, we can say that where moisture supply is the chief limiting factor (i.e. in arid, semi-arid and sub-humid regions), intensive agricultural methods are difficult to apply unless irrigation is also provided. Water is the first requirement: to the extent that water can be supplied or conserved, more intensive methods become possible. Without water, modern methods cannot do a great deal to increase crop production except by checking the destruction of soil fertility that only too frequently goes on under dry conditions, whether the agriculture is that of primitive or peasant farmers, or of the modern extensive type. Indeed conservation farming is the chief method of improving soil fertility in these regions. Where irrigation can be carried out, it offers great possibilities for improving soil fertility and crop production. However, the scope for further irrigation in the world is limited, whilst the installation of irrigation works is a slow and expensive matter, and damage to soil fertility from the development of waterlogging and salinity must constantly be guarded against.

The greatest opportunity for increasing crop production by modern intensive methods lies in the humid and per-humid regions. Here, deficiency of plant-food supply—not water-supply—is the chief limiting factor to soil fertility and crop production. This can be remedied relatively easily, rapidly, and cheaply, by the appropriate manuring; and by this means such soils can be raised to high levels of fertility.

In the most general view, ignoring the special needs of individual soils and crops, we can see that in agriculture the need and the effectiveness of inorganic fertilizers increases with increasing rainfall. This follows naturally from the increasing leaching of plant-foods from the soil. This observation provides a key to planning, in a broad way, the best distribution of fertilizers in the future; also to estimating where the ultimate fertilizer consumption is likely to be greatest, and where—subject to the supply of power and raw materials—the largest fertilizer industries are likely to develop. The U.S.A. provides a good example of this principle in operation, and the results of large field-experiment programmes show that it holds good also in India, in China, and doubtless in most other parts of the world. Australia and South Africa are the chief exceptions: although under dry climates they have large phosphate requirements owing to deficiences in the rocks from which the local soils are derived.

The best methods to follow in applying the principles of modern intensive agriculture vary in different climatic zones, and in the tropics and

sub-tropics much detail has still to be worked out. There is no doubt that suitable methods will be found, where they do not already exist, and this will make possible large increases in crop production in the more humid parts of the earth, outside the frigid zones.

The greatest need for improved soil fertility and increased crop production is in Monsoon Asia—from India to Japan—where populations are large and rapidly increasing. In Japan, the application of modern methods is already well advanced. For the rest of Monsoon Asia, the writer estimates on a basis of experimental results that crop yields could rapidly be increased by 25 per cent. at a conservative estimate, by the introduction of moderate amounts of inorganic fertilizers, organic manures (where they are not already used), better crop varieties, and control of weeds, pests, and diseases. In time an over-all increase in crop yields of at least 50 per cent. could be secured, again at a conservative estimate, by a fuller application of these methods. There is no question that this can be done: what is needed now is action. To secure these increased yields will require a large and well-organized farm advisory service, and a large fertilizer industry: such developments as these should be pushed ahead as fast as the governments concerned can do so [78]. If this is not done, the populations will outgrow the food supply, and nothing can avert a succession of famines of constantly increasing severity.

Outside of Monsoon Asia, and perhaps the U.S.S.R., rapid population increase is not at present such an urgent problem. However, large increases may occur in the future, especially in Africa and in South America: here also the same general principle holds good, that when large increases in food production are required, they will most easily be secured in the more humid parts of these continents by applying the methods of modern intensive agriculture. In the torrid zones, this will doubtless be done in combination with a greater cultivation of paddy rice, wherever soil and rainfall conditions permit.

Acknowledgements

In this account an immense field has had to be covered, and the statements made are based both on the writer's own experience and observations, and on information he received on his study tour or obtained from the literature. To give complete references or acknowledgements for every statement would require altogether too large a bibliography, so only selected sources can be mentioned. The writer expresses his gratitude and his regrets to the many colleagues who supplied valuable information during his tour, but whose names do not appear. He acknowledges here also the research grant given by the British Council, which made the tour possible.

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MANURING HEVEA IV: CONSPECTUS OF EXPERIMENTAL IMPROVEMENTS ACHIEVED IN MATURE STANDS AT THE END OF TEN YEARS, WITH A SPECIAL NOTE ON SEED PRODUCTION[1]

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General benefits.—The general benefits to mature rubber trees that can be procured by nitrogenous manuring have now become well-established knowledge. The accompanying Fig. 1 conveys a good visual idea of a comparison between manured and unmanured trees on the same site. It was originally drawn from photographs taken at the edge of experimental plots where felling of adjacent trees for replanting had given a clear exposure. The trees were 18 years old and had been

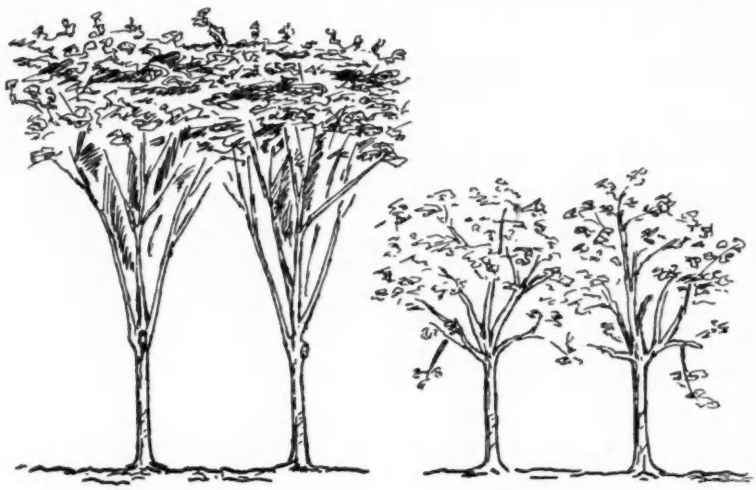

FIG. 1. Manured. Unmanured.

annually manured for the last 10 years, which corresponded to the period of tapping. The original uniformity is indicated by the same height of branching on both plots although the final heights are so different. The unmanured trees have retained the so-called 'orchard' shape because the poor foliage has let in enough light to maintain activity in the lower and interior branches. Walking is obstructed on these plots. In strong contrast with this the manured trees carry a dense foliage on

[1] The original manuscript of this paper was prepared in 1941 with new details of foliage measurements and soil analyses, but was lost by enemy action. This revival is deprived of a considerable part of the critical evidence, but retains all the main conclusions.

branches high overhead. The obvious differences in vigour are reflected in similar differences in bark renewal and sappiness, which form the chief basis for the final effects on yield. These often only come fully to light as the cycle of tapping reaches bark which has felt the benefit of manuring from its earliest renewal, so that final assessments should be reserved until after a full tapping cycle has been accomplished.

When manuring is started in backward areas like that of the unmanured trees depicted above, then the first effect is an improvement of the foliage of the lowest branches. The improvement soon spreads to the upper parts of the trees, followed by a shading out of the lower and interior branches. The first few years are marked by a great litter of these dead twigs and branches. The increased leaf-fall, too, produces in the course of time very evident soil changes, bringing back a good earthworm population and a dark surface-layer when these have been lost under former depleted and eroded conditions. In this sense a purely inorganic application of sulphate of ammonia will produce profound ultimate organic benefits.

Measured benefits.—The main conclusions are sufficiently exemplified by one series of 11 experiments, the layout and details of which have previously been described [1, 2, 3]. Known as the 25-plot experiments, they were started in 1930–1 and manured yearly until interrupted in 1941, just at the time when a new page of their history would have been opened on bark which had been benefited during the critical earliest stages of renewal. The latest measurements were based on sampling of individual trees, and in Table 1 are given the grand averages for

TABLE 1. *Average Effects in 11 Experiments after 9 Years of Annual Manuring. Not corrected for Poaching*

	Yield gm.-tree-tapping	*Yield effect*	*Growth effect cm.*
A O Control	11·98	..	..
B N	17·76	5·78	10·78
C NK	16·98	5·00	8·34
D NPKX (organic)	16·44	4·46	14·03
E NPK	18·42	6·44	13·56
Standard error	..	±0·40	±1·24
Average effect	..	5·42	11·68
Range, various experiments	..	3·0–9·0	8·4–18·9

yield and growth (girth) effects. Before further discussion it must be stated that every recent work [4] has shown that poaching of manures across plot boundaries has given the controls such benefits that correction of the records becomes a very important consideration, operating always to improve the findings. The available tests on unaffected trees at plot *cores* were only of a preliminary nature, but they were sufficient to warrant the conclusion that the control yield shown in Table 1 is overassessed by at least 1 gm.-tree-tapping, giving a correction to the general result of some 20 per cent. The clear conclusion is that nitrogen has

quite outstanding importance and that, although the addition of phosphate improves girthing, none of the additions to nitrogen have provided practical yield increases. In particular the question implied by the inclusion of the organic treatment (viz. has an organic manure some peculiarity to outweigh its lower nitrogen efficiency and its higher cost?) is answered definitely in the negative.

Under a system of continuous alternate-day tapping the yield benefit has built itself up during 9 years' manuring to a value of 5·42 gm.-tree-tapping (uncorrected). When corrected this corresponds to a general gain of at least 200 lb.-acre-ann. The experimental manuring has been extravagantly heavy, if viewed from a commercial angle, whilst the areas were not originally chosen as needy ones but as widely representative of all grades. Thus it is evident that any commercial and economical use of fertilizers, made with the knowledge now gained, would secure a far more remunerative return than this experimental average. Even so, it would be highly remunerative in normal times. Reduced to the broadest terms, the application of each 1 lb. of sulphate of ammonia (say 4 cents expenditure) is, after a course of years, resulting in ½ lb. of extra rubber (say 13 cents return).

The history of the experiments shows that, although the foliage improvements were general and rapid, the yield-increases were immediate only in the case of the younger stands on very depleted (previously cultivated) sites. The yield advantages in medium stands are realized not so much in raised yield-levels as in proper maintenance of yields against an otherwise inevitable deterioration. The economic fundamentals of a field of rubber change but slowly, and treatments like manuring must be undertaken with long views. The comparisons obtained by means of the writer's technique of foliage measurement [4] reinforced this interpretation. Whereas the quality of the sites of the experiments varied between foliage values of 12 to 32 per cent. of the arbitrary standard used, as revealed by the controls, yet the manured plots on all sites had been raised to, or maintained at, a closer level of uniformity with values around 56–64 per cent.

The only case of negative result was in an experiment upon a site of river clay with impeded drainage; a limitation which seems insuperable. The foliage in such cases may respond to manuring, but bark quality and yield do not respond.

Seed production.—Seed-counts were made in Nov. 1941 in 3 experiments and are worth recording for the light they throw upon the question of nitrogen alone versus a complete fertilizer for mature trees. A light frame was made, thrown on the ground under the trees at random, and the seeds and shells lying within it counted. This was continued until each plot had been adequately assessed. The number of shells was in slight deficit on the seed-count, so that this check had no particular value. Table 2 brings together data on seed, growth, foliage, and yield for one experiment which is typical, except that yield-response is rather low, due to poor aeration of a very close soil. Foliage is doubled by manuring; whilst for this factor and for yield practically a full effect is attained by the nitrogen alone (treatment B). In sharp contrast with

this the seed production is not affected by nitrogen although the complete fertilizers more than double it. In this result phosphate presumably performs the chief function. Effects on girthing are intermediate, nitrogen producing some effect, but the inclusion of phosphate as well giving a much larger one. Considering that the large quantity of nutrients in the seed is deflected from other uses in the tree, such as the restoration of latex loss, and is lost at least partially from circulation on

TABLE 2. *Average Treatment Effects in a Typical Experiment*

	Seed: 10^3 per acre		*Growth: cm. girth*		*Foliage: per cent. of arbitrary standard*		*Yield: gm.-tree-tapping*	
A O Control .	21·1		91·9		29·2		10·33	
B N . .	21·8	0·7	98·8	6·9	61·1	31·9	14·55	4·22
C NK . .	19·6	−0·5	97·6	5·7	58·0	28·8	12·27	1·94
D NPKX .	45·3	24·2	108·7	16·8	68·4	39·2	13·14	2·81
E NPK . .	47·0	25·9	103·0	11·1	71·5	42·3	13·47	3·14
S.E. . .	±3·9		±1·7				±0·47	

the site, it is easy to see why the results on yield of sulphate of ammonia alone have compared so favourably with the results of the 'complete' treatments, which might be favoured on general grounds. Phosphate has proved to be generally essential to the early growth of young rubber trees in Malaya [5], but in the later mature phases it must obviously be used with discretion or the trees may be stimulated in directions which have no significance for ordinary estate production, yet take their toll in the nitrogen economy of the trees.

These conclusions are supported by the seed-counts in two other experiments, given in Table 3. It is interesting to note that the highest

TABLE 3. *Seed-counts in 2 Experiments*

Age of experimental trees .	18 yrs.	24 yrs.
Quality of site . . .	Fairly good	Very poor indeed
Girth of control trees . .	95·4 cm.	79·5 cm.
Foliage of control trees . .	20 per cent.	12 per cent. of standard
Foliage of manured trees .	65 per cent.	52 per cent. of standard
Seed, thousands per acre:		
A Control . . .	22·3	18·6
B N	21·5	50·3
C NK	25·4	52·8
D NPKX . . .	31·4	80·2
E NPK	34·0	85·5
S.E.	±2·7	±6·0

seed production is from the manured plots of the worst site of all; the early conditions of hardihood have apparently stimulated the reproductive phase. Without manuring the trees are derelict but respond in all ways, even to nitrogen alone.

It may be pointed out that the reduction of foliage responses to numerical measurement, made possible by my technique [4], will permit

of new calculations, of which the following is an example. It was found that a single dressing of sulphate of ammonia carrying about 60 lb. of nitrogen per acre to a needy stand of trees will result in an improvement of foliage by about 10 units on the arbitrary scale used. If we consider the total amount of nitrogen in the living leaves, Page's rough calculation from Dyck's analysis of a single tree leads to 400 lb. of nitrogen per acre. The writer considers this a high estimate because Dyck's specimen was too large for a stand of 100 per acre, and suggests 275 lb. as an amendment. A foliage value of 55–60 units could be assigned to such a stand, which allows us to assess each unit of foliage on our scale at 5 lb. of nitrogen per acre. Then a dressing of 60 lb. of nitrogen might, if fully utilized, lead to an improvement of 12 units, and this accords sufficiently well with the finding of 10 units to give an interesting hint of the possibilities when more accurate data are available.

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CARP FARMING IN PALESTINE

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Introduction.—The early history of carp culture in Palestine was referred to in Hornell's Report of 1934[1]; the present paper deals with its expansion during the last six or seven years. The author hopes that it may serve as an introduction to the appreciation and study of a mode of farming which is worthy of wide extension in many warm lands.

The knowledge and practice of fish farming in Palestine is entirely the result of Jewish effort and enterprise. Immigrants from Central Europe naturally brought with them knowledge and experience of pond culture in Austria, Yugoslavia, and elsewhere. This experience they have put into practice with most profitable results. There is still much to learn, by experience and by deliberate experiment, in the new surroundings, but pond culture has already more than proved its worth.

Service with the Fisheries in Palestine, from November 1940 until January 1944, was an experience full of interests, one of which was to watch over the extremely rapid development of carp farming in those war years, both in area of productive water and in the tonnage marketed.

Fish farming in Palestine has to contend with peculiar difficulties, not all of which have yet been surmounted. The enthusiasm of the immigrant pioneers knew no bounds when it was realized that in the warm climate of the new land the fish would grow two or three times as fast as in the ponds of Central Europe. But in Europe water was not limited: in Palestine it is. Irrigation-water is the life-blood of much of the most productive land in Palestine, and besides being strictly limited in quantity, it is distributed in complicated ways; rotas are involved and *ab antiquo* usages. The ground, where land-settlement has been completed, is often owned in minute parcels, each of which requires water but does not necessarily receive it as of right, because land and water have for long been commodities that can be separately bought and sold. The legislation is complicated, and is under gradual and difficult amendment, in which many wider interests are involved. Psychologically, too, there were and are difficulties. It is very difficult for an untutored peasant, tilling the land with ox and ass and nail-plough, as his ancestors have done since time immemorial, to realize that he is none the worse off when a group of immigrants surround their parcels with earth-walls and make a lake where was dry land before. Surely, he reflects, irrigation-water in this district is scant and precious; some of the water in that new lake must have been stolen from me; how else could there be such volume? It is of little use emphasizing that evaporation from a water-surface is not necessarily greater than from a growing,

[1] *Report on the Fisheries of Palestine*, by James Hornell. Jerusalem 21. 11. 34. Published on behalf of the Government of Palestine by the Crown Agents for the Colonies, 1935. Price 7*s*. 6*d*.

irrigated plant crop, and that the neighbouring new ponds represent only a different method of using the same quantity of water. In such affairs Governments must be circumspect; and that is galling to the proper enthusiasm of the pioneer. Much more might be said along these lines, but so much is necessary if only to explain the peculiar, and otherwise seemingly irrational, shape of some of the fishponds in Palestine, particularly in the Beisan district.

There is no need to enter into the details of the administrative system whereby fishponds are constructed under licence. But one reason for the licensing system, and indeed for some early opposition to pond developments, must here be mentioned. Palestine was a highly malarial country and potentially still is. Fishponds would, it was argued, increase again the malarial danger. This contention was properly refutable so long as the ponds were well maintained.

The chief point, here to be stressed, is that fresh-water fish culture has been carried forward with enthusiasm in an area abounding in peculiar difficulties. That these have been overcome is due, primarily, to a widening appreciation of the value of this form of farming.

The use of land for fish farming.—Though sometimes ponds can occupy land that is otherwise unsuitable for agriculture, e.g. marshy land, in the main fish culture is in direct competition with other methods of food production on irrigated agricultural land.

The use of land for fishponds is not to be compared with the laying down of citrus groves or forest plantations, for the crop is quickly grown and the land may at short notice be changed back from fish to another crop. Though not yet practised except rarely, it may be that a regular alternation between fish and vegetables will be found desirable. The initial cost of containing walls and banks, sluices and channels, in normal times, is not high, and they do not deteriorate badly when not in use.

Fish farming, or carp culture, should, in fact, be looked upon in the same way as any other form of food production. The farmer chooses the variety of his crop as he thinks expedient, having regard to type of land, availability of water, price, need, and so on.

In Palestine the total land now under carp amounts to about 8,000 Palestine dunums (the equivalent of 2,000 acres or 800 hectares), producing at the rate of 1,200 tons a year. More then 80 per cent. of this area belongs to Communal Jewish Settlements, the remainder being in private ownership. The distribution of the ponds throughout Palestine is now roughly: 500 acres north of Lake Huleh; 1,175 acres south of Lake Tiberias and around Beisan; 250 acres in the coastal plain; and 75 acres in the region immediately north of the Dead Sea.

Fish farming and public health.—In ideal circumstances there is no clash of interests in theory, nor need there be in practice, between well-maintained fishponds and public health, including the control of mosquitoes. In the Dutch East Indies the building of fishponds, it is said, has been used as a cheap, simple, and efficient method of dealing with malarial swamps. In well-managed ponds conditions are unsuitable for the growth of mosquitoes.

The chief points to be watched, in the proper maintenance of fishponds, is that there should be no emergent vegetation around the pond margins at water-level. If water-supplies permit, the water-level of every pond should be raised and lowered by about a foot within each week as an additional precaution.

In Palestine, where the Government Department of Public Health and Settlements and individuals had, over many years, fought a vigorous and highly successful battle against the mosquito, the advent of fishponds was watched with some trepidation and distaste. This was fully overcome by the earlier ponds being well maintained and demonstrably free from mosquitoes. Later, in a few instances, less than adequate care has been taken and the censure of the Department of Health has been evoked. It is evident that experience is insufficient for the proper control of vegetation in the ponds. Perhaps it will become necessary in all cases to dry out the ponds completely for several months every few years in order to keep aquatic vegetation in check, and prevent the appearance of conditions favourable to the mosquito. Experience alone will show if such a régime has any important effect on the biological fertility of the ponds.

The carp.—So far the European carp, the species chiefly used in the farms of Central Europe, is the only fish which is cultured in Palestine. Other species will no doubt soon be tried and some may perhaps be found superior, but the success of this species in Palestine is indisputable. Its rate of growth is roughly two to three times what it is in the colder waters of Europe.

In the fish farms of Europe several varieties of carp are used, and these were imported into Palestine. There is, I think, no evidence to show that under Palestine conditions any one variety is markedly superior to any other; as a result, or perhaps in proof, of which, I believe that there are now no pure stocks in Palestine of any one of the European varieties. The housewife, as a matter of convenience, prefers fish with a minimum of scales so long as enough are present to avoid any suggestion that the fish is 'scaleless'.

The carp is much esteemed by the immigrant population of Palestine, but the Arabs prefer sea fish. The carp is not usually to the taste of Britons, but some will attest its merits. To the newcomer the chief disadvantage of the carp at table is the multiplicity of its forked and barbed bones, though the regular carp-eater finds these no burden. In this regard the carp farmers of Palestine state that since their fish grow so swiftly the bones have not time to calcify completely, so that they remain soft and of little trouble in the mouth or stomach.

Pond construction.—The most convenient and cheapest method of making fishponds is to use flat or very gently sloping agricultural land, and to build up the banks with a bulldozer or tractor and scraper. The last-named is preferable because the tractor is forced to run frequently along the tops of the banks in process of building, thus well consolidating the new banks and minimizing horizontal seepage. In any event, seepage decreases eventually with the natural consolidation of the banks. With some types of soil, however, seepage may be serious. It must be

carried away by well-cleaned drainage channels, otherwise conditions favourable to the breeding of mosquitoes are easily set up. Sometimes it may be desirable to insert a puddled clay core in the banks to prevent seepage. This has not been the practice in Palestine and is of doubtful necessity under local conditions, though sometimes certainly desirable. The cost would be considerable.

The average depth of the ponds is 1 m. The banks must be somewhat higher than the intended depth of the ponds, and they are usually about 1½ m. wide at the top, to allow the passage of carts. The banks are given a slope of about 45° at the time of construction, but this slope gradually flattens out under the influence of ripple erosion.

Ripple erosion is important and may be serious, rapidly eating away new earth-banks. The use of a stone band at ripple-level might be helpful, but so far expense has precluded a trial. Frequently in Palestine attempts are made to minimize ripple erosion by placing in the water's edge rows of straw bales staked into position. This artifice is certainly for a time effective, but is not desirable, since, like standing vegetation, it is helpful to and harbours mosquito larvae.

Inflow and outflow of water take place through concrete pipes. Each pond is usually, and preferably, arranged to allow of complete and easy emptying. A sump or depression is arranged around the outflow, and in this the fish collect as the water is drained away. The outflow itself is normally made in the form of a square-section concrete tower, one side of which is open and bears slots. These slots hold sluice boards to keep up the water to any desired level, or metal grills to retain the fish while emptying.

Ponds are usually and most conveniently built in groups in order to minimize costs and labour. The construction of the banks is the chief cost, so that a pair of adjacent ponds which share a bank is at once a saving over the construction of two separate ponds. Likewise the bigger the pond the shorter, and therefore the cheaper, is the bank in proportion to unit area.

In Palestine the average size of the individual fattening ponds is perhaps 5 acres, but many are smaller than this, and a few are very much bigger. As a rough example, it may be pointed out that a square 10-acre pond is bounded by a bank which is roughly 800 m. long. If it is assumed that the bank is 1½ m. high in order to retain 1 m. depth of water, it should be 1½ m. wide at the top and have an initial slope of about 45° on each side. Such a bank will contain about 3,600 cu. m. of earth. In calculating the cost, allowance will then have to be made for inlet and outlet sluices, and probably for some length of open channel conveying water from the source of supply.

It is not possible to provide any figure of actual costs in Palestine which would be helpful to others. During the war years, which have seen the main development of carp ponds, labour costs have been abnormally high. Further, the economic régimes of the Communal Settlements, which are the chief promoters of fish farming, do not lend themselves to exact analysis for the costing of single items on any ordinary basis.

Water-supplies.—Palestine, being a land with water problems, both of supply and distribution, does not provide naturally favourable conditions for fish farming apart from the warmth of the climate and the enthusiasm and experience of the immigrants. Fish farming in Palestine started on a successfully sustained commercial scale in the Beisan region, i.e. in the eastern part of the Emek or broad valley which runs across the country from the back of Haifa Bay to the Jordan depression. From the point of view of easy development this was almost the worst possible region owing to the fine parcellation of the land and the complication of the *ab antiquo* usage of a strictly limited water-supply. However, fishponds in that region now form a part of the normal agricultural activity of a large proportion of the Settlements.

From the Beisan region, fish farming has spread in particular to the region north of Lake Huleh, where water is in ample supply, to the region around the southern end of Lake Tiberias, to the coastal plain, and to the north end of the Dead Sea. The last of these regions is of particular interest since the area is one of extreme aridity. A Settlement, engaged primarily in the Potash Works, has added fish farming to its activities, pumping water from the Jordan just before it runs into the Dead Sea. The water is directed into certain natural depressions which, with little modification, form adequate fishponds.

The water in the fishponds is static and not flowing. Normally, enough water is added just to make good the total of losses by seepage and evaporation. The former decreases greatly with the increasing age of a pond. Roughly speaking, carp will flourish in any water which is potable by man. They will flourish in certain waters, of which the Asi spring in Palestine is an example, whose salinity is considered too high for constant use in irrigation. There is evidence, however, that there may be some saline accumulation, directly or indirectly, inimical to fish, in the pond beds after a few years of uninterrupted use. There have recently been important losses through this cause, and experience is still being gained.

Wind action and moderate plant-growth usually keep the water well oxygenated. On a few occasions in Palestine there have been sudden serious losses of fish which seem to have been caused by the development of very heavy crops of algae in mid-summer. Then if the weather is calm and there is no wind action to stir the water, a serious oxygen shortage may develop in the early morning, leading to the death of the fish. No complete and immediately practical method for control of the algae is known, but the problem is being studied.

The measurement of evaporation from the ponds is not easy and accurate knowledge is lacking in Palestine. The importance of evaporation is great in view of the acute water-shortage prevailing in parts of the country. It may be argued, perhaps, that, when in short supply, water-use should be related as nearly as possible to maximum production of food rather than maximum economic gain by means of a crop which has especially heavy water-demands. So far in Palestine, figures of sufficient accuracy are not available to enable direct comparison between the water-consumption of an acre of fishpond and an acre of, say, bananas under irrigation.

Growth, yield, harvesting, and management.—Experience in Palestine seems to show that the management of carp ponds up to a moderate standard of efficiency is probably more a matter of common sense and quick learning than of long experience. But to get the best results the value of long experience is clearly not to be denied.

It is worth noting that fish are believed to be more efficient converters of fodder into food fit for human consumption than any other domestic animal, this being particularly true of the protein fraction of the fodder.

Though deliberate experimental work is in progress, the data available on food consumption, as on much else, is still inadequate. In general it is believed in Palestine that in most ponds and with moderate stocking the carp obtain rather less than half their total food from naturally occurring aquatic organisms. Manuring of the ponds to increase the supply of aquatic organisms is frequently practised. Inorganic fertilizers, animal dung, and human sewage are all used on occasion, but experience is not yet enough for this practice in Palestine to have settled down to a regular technique.

The main part of the carp's food is met by the addition of protein-containing fodder. It is reckoned that with moderately good food 3 to 4 tons of it will give a return of 1 ton of fish flesh. The best food is considered to be crushed and soaked lupin seed. Maize is the next most highly regarded food. In war-time Palestine the usual food has been the cotton-seed residue from the factories after expression of the oil. The aim is a cheap fodder containing protein not available for man's consumption other than through the agency of the carp. A very oily or fat fish is not desired.

In each pond the fish are fed daily at the same spot, marked by a stake. By scooping up water from the bottom, with a tin on a stick, it is possible to judge whether the fish have cleared up their last meal and so to determine how much new food should be provided.

Carp are most accommodating animals and will grow in almost direct proportion to the food eaten, this itself being dependent on the temperature. Lack of food simply inhibits growth temporarily. Under Palestine conditions of temperature and feeding, growth is extremely rapid. The fish will grow from the egg to between $\frac{1}{2}$ and $\frac{3}{4}$ kg., the most popular market size, in about 8 months under the best conditions. A conservative figure for yield is $\frac{1}{2}$ ton per acre for the main growing-season from March to October. This represents, for example, the growth of 1,000 fish from the egg to $\frac{1}{2}$ kg. Bigger yields are now frequent in Palestine. The optimum number of fish per unit of area is still a matter for further experiment, and as yet there seems to be no concensus of opinion on the matter.

In the European system of management, spawning ponds are normally used. These are small ponds into which a pair of well-grown fish are released in the spring. Particular attention is paid to the selection of the female. Spawning quickly takes place, and the adult fish are then removed. The fry develop for some weeks or months in the spawning ponds with special food and protection, and are then transferred to stocking ponds or released direct into much larger fattening ponds. The

breeding-season is comparatively short, lasting about 6 weeks in spring. Young fish usually begin to spawn when they are about 12 months old. Though this European system may be regarded as the basis, in the warmer waters of Palestine it frequently happens that the fish breed at an earlier age and do so irregularly. In consequence the large ponds often come to contain an assortment of fish of differing sizes and ages, instead of the entire crop being of equal size and age.

Harvesting is most conveniently done by emptying each pond in turn. The Settlements in some regions do this by agreement, so that a steady flow of fish reaches the market over as long a season as possible, and large quantities are available at those festivals when the carp is in particular demand.

When a pond is to be emptied the water is gradually let out and the fish collect in the 'sump' around the exit. Thence they are easily scooped out with hand-nets or a small seine. The larger fish are stored for a while in a small pond or are sent off to market at once. The small fish are either transferred to another pond or the same pond can at once be refilled.

The immediate refilling of the same pond is perhaps not really advisable. It is probably better to allow each pond to dry out for a while and in this way secure greater control over the fast-growing aquatic vegetation, and over the water-snakes and tortoises which sometimes take a considerable toll of the small fish. The proper control of vegetation in and around the ponds has perhaps a secondary effect in making the ponds less attractive to a large variety of aquatic wild fowl. Certainly some toll of the young fish is taken by birds, but precise knowledge is not available as to the relative harm done by members of different species. Some species of the visiting water-birds are feeding mainly on water-snails and other non-piscine animals.

In some instances the water emptied from one pond was used, either because of the 'quality' of the water or because of its scarcity, to refill another pond from which the harvest had been taken earlier. Experience has, however, shown that this practice is not to be recommended, and almost all ponds now have an independent water-supply, and water is only used once. All movement of water is normally by gravity. The pumping of pond water is rare.

The transport and marketing of carp is simple and the particular method used is possible because of the hardiness of the species. The fish are all sent to market alive. An ordinary lorry is fitted with a canvas tank, made of tarpaulin, and this is filled with water. In practice a 5-ton lorry with a convenient amount of water can carry about a ton of fish. Oxygen is bubbled into the water through a rubber-tube connected with a cylinder. Losses *en route* usually do not exceed 1 per cent. The retailers have small tanks in their shops in which the fish are kept. The customer expects to receive the fish alive and in perfect condition.

The future of fish farming in Palestine.—There seems to be an important and stable future for fish farming in Palestine. Water-shortage is the only important difficulty, and this applies with less strength in the area north of Lake Huleh. The demand for fish is great

and growing and has never yet been satisfied. Experiment will gradually modify certain aspects of the technique, and perhaps other species besides the carp will become of importance. It is to be expected that much may be learned from Indian practice in particular, where the growth of the individual fish is often several times faster than in Palestine, though the yield per unit area is much the same. Pond fish is already an established crop in Palestine and doubtless will remain so, rising and falling in importance just like most agricultural crops.

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THE MANURING OF BEANS AND PEAS

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Summary.—A summary has been made of the results of all available experiments on the fertilizer requirements of beans and peas carried out in Great Britain. A small number of long-period experiments and several series of annual experiments, including some modern replicated trials, were available. These showed fairly conclusively that beans stand in high need of potash; the crop is distinctly more responsive to potash than cereals or even mangolds. Large increases in yield were generally obtained from farmyard manure (F.Y.M.); when the crop is dunged, no fertilizers are likely to give a remunerative response except in cases of extreme deficiency. Beans proved to be moderately responsive to phosphate, increases in the yield of beans from this fertilizer being of the same order of magnitude, relative to the mean yield, as those of mangolds. There is little justification for the use of nitrogen on beans.

The experimental evidence on the fertilizer requirements of peas is very scanty, and for the most part very conflicting. Under ordinary farming conditions peas appear to be able to make efficient use of phosphate and potash in relatively unavailable forms; it is doubtful whether the use of nitrogen will give any increase in yield, although it usually improves the appearance of the crop in the field. These conclusions must, however, be accepted with reserve until an adequate series of experiments has been carried out.

The second part of the paper reviews the current manurial practice on farms, based on data obtained from the Survey of Fertilizer Practice in the Bristol, Cambridge, and Leeds Provinces. Except in a few counties in eastern England, F.Y.M. was not widely used on beans; in these eastern counties only one-quarter of the acreage was dunged in 1941–2, compared with one-half in 1938–9. In the same period there has been a considerable increase in the use of phosphate on beans, and some farmers have begun to use nitrogen for this crop. Potash was not used on beans before the war, and very little of the potash now allocated to beans has been applied to the crop.

Peas generally received rather less F.Y.M. and more nitrogen and phosphate than beans. The changes in manurial practice which have affected peas during the war years have been similar to those for beans.

1. *Introduction*

The fertilizer requirements of the chief arable crops have been discussed by Crowther and Yates [1], who summarized all available experiments carried out in Great Britain since 1900. The present paper gives a short account of the experimental evidence on the fertilizer requirements of beans and peas, which were not covered by the previous paper. Although many fewer experiments have been carried out on these crops than on cereals and roots, sufficient are available to make an

examination of the data worth while. The effect of fertilizers on beans and peas is of particular interest in view of their importance as a source of home-grown protein; in addition, there has been in recent years a falling off in the yield of beans in many parts of the country, and the suggestion has been made that one of the contributing factors may have been manurial deficiency—especially shortage of potash.

2. *Fertilizer Requirements of Beans*

Only three long-term experiments on beans appear to have been carried out in this country. At Rothamsted beans were grown continuously and alternately with wheat on Geescroft Field for about 30 years from 1847 and in a four-course rotation on Agdell Field in the period 1854–82. At Saxmundham in East Suffolk beans are one of the crops of a four-course rotation experiment begun in 1900. The results of an early Danish rotation experiment on similar lines and of all available annual experiments carried out in this country have also been abstracted.

Rothamsted (*Geescroft Field*).—Apart from 2 years of fallow (1860, 1863) and 1 of wheat (1861), beans were grown continuously from 1847 until 1870. There are considerable practical difficulties in the way of maintaining a continuous series of autumn-sown crops; after 1870 these difficulties were increased by a run of unusually wet seasons and the experiment was abandoned a few years later.

There were 6 treatments arranged in systematic order as follows:

No fertilizer, nitrogen only, phosphate only, nitrogen + phosphate, phosphate + potash, nitrogen + phosphate + potash.

All the potash plots also received sodium sulphate and magnesium sulphate. Apart from minor changes in the form in which the plant-nutrients were applied, and in their amounts, the only change of treatment occurred in 1852–9 when no nitrogen was applied. In 1852 a further two plots receiving potash alone and potash with sodium sulphate and magnesium sulphate were added; these were discontinued after 1859.

Table 1 shows that considerable deterioration occurred in the yields of all plots during the course of the experiment, the unmanured plots in

TABLE 1. *Effect of Fertilizers on Beans grown continuously on the same Land, Geescroft Field, Rothamsted* (*Mean Yield in cwt. per acre*)

	o	*n*	*p*	*np*	*k*	*pk*	*npk*
1847–51 . .	14·0	14·4	13·5	13·1	..	19·0	20·0
1852–9 . .	4·1	..	4·7	..	6·2	7·7	..
1862–70 . .	1·8	2·1	3·6	4·0	..	6·1	9·3

the last period being practically a failure. Crops were good until 1852, when a series of poor yields was experienced even on plots with phosphate and potash. Excessive weed competition appears to have been one of the chief causes of the low yields, but Hall [2] has also suggested that the land may have become 'bean-sick'.

No benefit was obtained from phosphate in the first period and very little in the second, but it prevented the extreme deterioration observed on the unmanured plots after 1862; the field notes suggest that this was partially a maturation effect. From the outset the beans responded well to potash, the responses in each period being 50 per cent. or more above the yield from phosphate alone. Destruction of the weeds by fallowing effected a very great but temporary improvement in yield on the plots receiving phosphate and potash, but gave no improvement on the unmanured plots. The addition of sodium sulphate and magnesium sulphate on plots receiving potash had no effect on yield. Nitrogen had practically no effect until towards the end of the experiment.

Beans were also grown alternately with wheat from 1851 (wheat) to 1866, manures being applied to the beans only. Except that the nitrogen plots received this fertilizer throughout the experiment, the manuring was similar to that for continuous beans. Good crops of beans were obtained for the first 3 years, but subsequently the yields on all plots were generally poor. The wheat crops deteriorated little until towards the end of the period, when weed infestation became serious.

Table 2 shows the mean yields for the period 1852–66. The response to phosphate (which became more marked towards the end of the

TABLE 2. *Effect of Fertilizers on Beans and Wheat grown in Alternate Years, Geescroft Field, Rothamsted* (*Mean Yield 1852–66 in cwt. per acre*)

	o	*n*	*p*	*np*	*pk*	*npk*
Beans . .	6·1	6·1	7·2	7·9	9·6	9·7
Wheat . .	12·9	14·0	14·1	14·9	13·6	13·8

experiment) was somewhat larger than when beans were grown continuously, whilst potash showed a rather smaller effect (about 30 per cent. increase in yield). There was very little response to nitrogen. The residual effects on wheat were all small; the increased growth of beans on the plots receiving both phosphate and potash might have been expected to result in an improvement in the wheat crop, but there was in fact no increase in yield.

Rothamsted (*Agdell Field*).—An experiment in the form of a four-course rotation of beans or clover, wheat, swedes, and barley has been carried out at Rothamsted on Agdell Field since 1848. Only one course of the rotation is represented in one year. Beans were grown in 1854 and every fourth year until 1882, but in 1874 and 1882 the yield of grain was not recorded; subsequently clover has almost always replaced beans. The experiment gives information on the effect of phosphate (approx. 3 cwt. superphosphate per acre) and of a complete fertilizer consisting of superphosphate, ammonium sulphate, ammonium chloride, and rape cake, potassium sulphate, sodium sulphate, and magnesium sulphate. These manures are applied to the swedes only.

The average yields are shown in Table 3. Moderate yields were obtained from the complete fertilizer plots; phosphate alone had practically no effect.

TABLE 3. *Effect of Fertilizers on Beans grown in Rotation, Agdell Field, Rothamsted (Mean Yield 1854–70 in cwt. per acre)*

	a	*p*	*npk*
Roots fed on . .	6·7	8·3	13·8
Roots carted off . .	6·8	6·8	12·2

Saxmundham.—A four-course rotation experiment (beans or clover, wheat, mangolds, and barley) has been carried out at Saxmundham, East Suffolk, since 1900 on heavy soils derived from the Chalky Boulder Clay. The results have been discussed by Oldershaw [3, 4]. The design

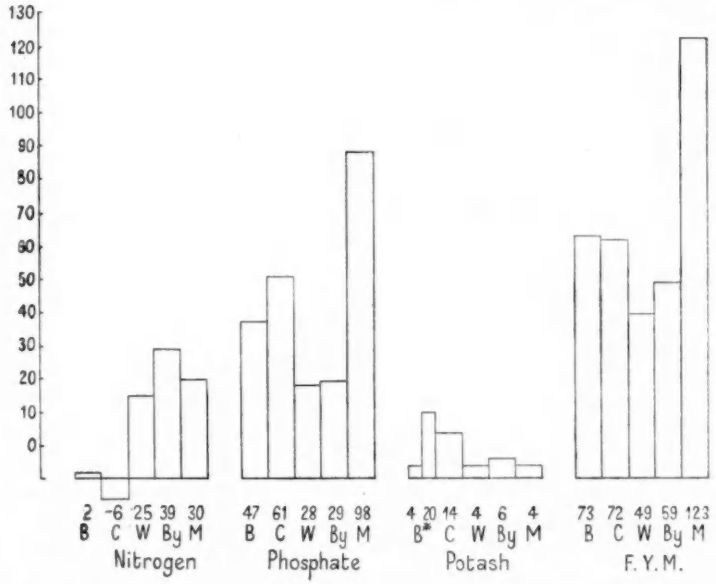

FIG. 1. Average responses of crops grown in rotation, as percentage of mean yield (Saxmundham 1900–36).

Key to crops:	*Rates of dressing (per acre):*
B Beans	0·3 cwt. N as nitrate of soda.
C Clover	0·3 cwt. P_2O_5 as superphosphate.
W Wheat	0·5 cwt. K_2O as muriate of potash.
By Barley	10 tons F.Y.M.
M Mangolds	

Left-hand column: response to potash in the absence of phosphate.
Right-hand column: response to potash in the presence of phosphate.

is factorial, with all combinations of nitrogen, phosphate, and potash applied annually; there is also a dunged plot. The information given by this type of experiment is of special value since it allows a comparison to be made of the responsiveness of different crops to the same combinations of fertilizer treatments. Thus, although conditions peculiar to the experimental site must determine to a large extent the magnitude of fertilizer responses, it is likely that the relative responses of crops vary from place to place to a very much smaller extent.

The average responses to each fertilizer component of the different crops in the period 1902–37 are shown in Fig. 1. Nitrogen has entirely failed to increase the yield of beans throughout the experiment, whilst the other leguminous crop, clover, shows a small but consistent depression in yield. Mangolds and the cereals, on the other hand, gave substantial responses to nitrogen.

All crops have responded markedly to phosphate, and there has been a large deterioration in yield on plots which receive no phosphate. The deterioration was most rapid in the case of mangolds, whose yields fell to a low level after very few years without this fertilizer. Unfortunately clover replaced beans in the years 1901–5, so that it is not possible to trace the early stages in the development of the phosphate response of beans. In the first year of the experiment, 1900, they showed no response, but in 1906 and subsequently very large responses were obtained. The effect of phosphate on the cereals was relatively small for the first 10 years, and it was not until the plots without phosphate were becoming very exhausted that the cereals gave large responses to this fertilizer.

Potash gave only small increases in the yield of mangolds, wheat, and barley. This makes the substantial effect of potash on beans and clover in the presence of phosphate the more striking. Mangolds, however, are usually fairly responsive to potash, but they have consistently failed to give any substantial increase in yield at Saxmundham, due almost certainly to the use of nitrate of soda as the source of nitrogen.

All crops responded well to F.Y.M., and the yield of beans with F.Y.M. was consistently greater than with a complete fertilizer.

Danish experiment.—A rotation experiment was carried out in Denmark by B. S. Jørgensen [5] in the period 1863–82. The design was similar to that at Saxmundham except that instead of potash alone there was a 'mixed-alkalis' treatment consisting of sulphates of sodium, magnesium, calcium, and potassium. The results are shown in Fig. 2. The soil was a light to medium loam, and provided conditions very different from those at Saxmundham. No crops gave any substantial response to phosphate, and there was even a slight decrease in the yield of beans and mangolds. The most interesting feature of this experiment is to be found in the responses of the different crops to the 'mixed-alkalis' treatment, which is presumably a potash effect; there is a marked contrast between the large effect of this treatment on beans (37 per cent.) and the entire absence of an effect on wheat and barley; even mangolds showed only a moderate increase from this fertilizer (10 per cent.). The effect on beans was considerable (15–20 per cent.)

at the outset of the experiment and became very large in the later years.

Barley and mangolds gave good responses to nitrogen, and wheat showed a small response, but the yield of beans was slightly depressed by this fertilizer. F.Y.M. gave similar relative responses for beans and mangolds; both crops showed considerably greater responses than the cereals.

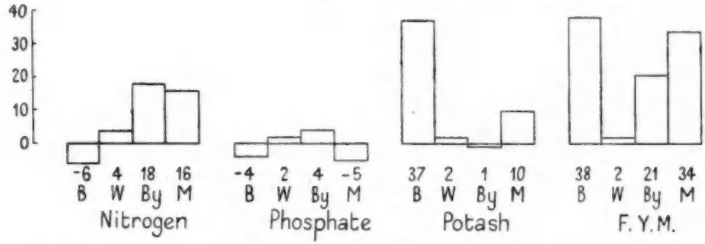

FIG. 2. Average responses of crops grown in rotation as percentage of mean yield (Denmark 1863–82).

Key to crops:	*Rates of dressing (per acre):*
B Beans	0·3 cwt. N as sulphate of ammonia.
W Wheat	0·25 cwt. P_2O_5 as superphosphate.
By Barley	0·9 cwt. K_2O as sulphate (+sulphates of sodium, magnesium, and calcium).
M Mangolds	Approx. 10 tons F.Y.M.

Annual experiments.—In addition to the long-term experiments just described, a few annual experiments [6, 7, 8] have been carried out on beans in Great Britain. With the exception of some recent Rothamsted experiments all these were simple experiments carried out before 1914.

Five replicated experiments having all combinations of F.Y.M., nitrogen, phosphate, and potash (10 tons F.Y.M., 0·4 cwt. N, 0·6 cwt. P_2O_5, 1·0 cwt. K_2O) were carried out at Rothamsted in the year 1935–45, and another factorial experiment with F.Y.M., nitrogen, and potash, having phosphate as a basal manure, in 1934. The mean yields and the main effects and first order interactions are given in Table 4. In 1935 and 1939 there were substantial effects of F.Y.M. and of potash, and indications of a negative interaction between the two. Phosphate had little effect except in 1937, when there was also a positive interaction with potash; the positive interaction of F.Y.M. and phosphate in 1936 is probably fortuitous. Nitrogen had no effect or slightly depressed yield when used alone, but gave a small increase in the presence of F.Y.M.

The other annual experiments were designed to test the effect of phosphate alone, the effect of potash in the presence of phosphate, and the effect of nitrogen in the presence of both phosphate and potash; the effect of F.Y.M. was also tested. The results are presented in

TABLE 4. *Effect of Fertilizers and F.Y.M. on Beans in Annual Experiments at Rothamsted showing the Mean Yields, Main Effects, and First Order Interactions*

	1934	*1935*	*1936*	*1937*	*1939*	*1945*	*Mean (excl. 1934)*
Mean yield	18·1	21·0	16·8	29·0	25·9	23·9	23·3
D.	2·7	5·6	−0·1	2·0	4·0	3·5	3·0
N.	0·3	1·2	−2·2	0·4	0·6	0·4	0·1
P.	..	−2·0	0·3	3·3	−1·0	0·4	0·2
K.	−0·4	2·7	−0·3	2·4	1·7	1·0	1·5
D.N.	0·4	1·9	0·7	0·4	0·8	0·2	0·8
D.P.	..	−0·2	2·0	0·4	0·3	−0·7	0·4
D.K.	0·5	−1·4	−0·4	1·7	−0·7	−0·3	−0·2
N.P.	..	−1·9	1·1	−1·2	0·6	0·2	−0·2
N.K.	2·9	1·6	−0·7	0·5	0·2	−1·3	0·1
P.K.	..	−0·2	0·6	2·0	0·0	−0·1	0·5

Table 5, which also shows the mean of the Rothamsted experiments already quoted, to which have been added the results of two others testing the effect of phosphate and potash on ploughed-up grassland. Since the amount of fertilizer applied varied from experiment to experiment, crop responses at different levels of dressing have been converted to standard dressings by means of the average response curves used by Crowther and Yates [1].

TABLE 5. *Effect of Fertilizers and F.Y.M. on Beans (Annual Experiments). Responses to Standard Dressings (0·25 cwt. N, 0·50 cwt. P_2O_5 and K_2O, and 10 tons F.Y.M. per Acre) in cwt. per acre*

Basal manuring		*Nitrogen pk*		*Phosphate —*		*Potash p*		*F.Y.M. —*	
	Year	*No. of Expts.*	*Resp.*	*No. of Expts.*	*Resp.*	*No. of Expts.*	*Resp.*	*No. of Expts.*	*Resp.*
Rothamsted	(1934–45)	7	−0·1	7	0·0	8	2·9	6	1·4
Cockle Park	(1906–9)	..	..	3	5·8	3	3·9	3	9·0
W. of Scotland	(1905–6)	18	0·6	8	0·6	8	1·8	8	3·1
Essex	(1896–8)	8	−1·1	13	1·3	13	0·3	13	2·0

The experimental results support the evidence obtained from the long-term experiments that nitrogenous fertilizers are of little value for beans. From the results of the Cockle Park experiments on land known to be responsive to phosphate it is evident that phosphate may, in suitable conditions, produce large increases in yield, but its effect was relatively small in the other experiments. Only the Essex experiments failed to show a substantial return for potash in the presence of phosphate. The effect of F.Y.M. was very variable, but gave considerable increases at the northern centres. On the average the use of F.Y.M. slightly reduced the response to phosphate and considerably reduced

the response to potash, but owing to the wide variation from experiment to experiment these averages are of low accuracy.

	Response to phosphate			*Response to potash*	
No. of expts.	*Alone*	*With F.Y.M.*	*No. of expts.*	*Alone*	*With F.Y.M.*
20	1·3	1·2	12	1·8	0·6

A recent experiment at Rothamsted on various bulky organic manures, in which the plots were split for nitrogen and potash, has strikingly confirmed the results of the earlier experiments just described. The yields are summarized below:

Mean yield without potash and response to potash (cwt. per acre)

	No F.Y.M.		*With F.Y.M.*	
	Yield without potash	*Response*	*Yield without potash*	*Response*
Barley (1943)	31·2	0·0	36·8	1·8
Beans (1944)	6·6	8·7	25·6	0·4
Wheat (1945)	31·0	0·3	37·2	0·4

Mean yield without nitrogen and response to nitrogen (cwt. per acre)

	No F.Y.M.		*With F.Y.M.*	
	Yield without nitrogen	*Response*	*Yield without nitrogen*	*Response*
Barley (1943)	25·9	10·6	34·4	6·4
Beans (1944)	11·3	−0·6	25·5	0·6
Wheat (1945)	25·6	11·1	32·9	8·2

Beans gave a large response to potash and were practically a failure in its absence, but neither barley nor wheat gave any response. Similarly, F.Y.M. trebled the yield of beans, but produced increases of only 20 per cent. for the cereals; the negative interaction between F.Y.M. and potash was very marked. Nitrogen, on the other hand, had no effect on beans, while producing considerable increases in the yield of barley and wheat.

In view of the small number of annual experiments available in this country a search was made through the more likely journals of the Scandinavian countries and of the United States in the hope of obtaining a series of experiments on beans similar to those on roots and cereals included in the paper by Crowther and Yates. The result of this inquiry showed that since 1900 there had been an equal neglect of fertilizer experiments on beans and peas in Sweden and Denmark as in this country. A fair number of experiments on various types of peas and beans were discovered in United States publications, but the standards of experimental design and reporting were so poor that they provide little

useful information. The only series which appears sufficiently reliable to be worth inclusion here was carried out on white pea-beans (a bush type of haricot bean) in Michigan during the years 1921–37 [9]. This series includes more than 60 individual experiments for which the mean responses to the standard fertilizer dressings were:

Response to:	*Nitrogen*	*Phosphate*	*Potash*
Basal manuring	pk	..	p
Response (cwt./acre)	−0·1	0·7	0·8

Here also was no increase in yield from the use of nitrogen, but there was some effect of both phosphate and potash, which both gave responses equal to 8 per cent. of the mean yield.

3. *Fertilizer Requirements of Peas*

The practical difficulties in conducting experiments on peas have led to an almost complete absence of fertilizer experiments on this crop. The early experiment (1847–50) on Geescroft Field, Rothamsted, a rotation experiment [10] on light land near Bramford, East Suffolk (1893–1907), and the results of some recent annual experiments are the only ones worth discussion here.

The Rothamsted experiment on peas was of similar design to that already described for beans. Crops were fairly good each year, the average yield being 13 cwt. per acre. The results over the four years 1847–50 were as follows:

Response to:	*Nitrogen*	*Phosphate*	*Potash*
Basal manuring	mean $\begin{matrix}0\\p\\pk\end{matrix}$	..	p
Response (cwt./acre)	−2·0	1·7	−0·6

There was a fair response to phosphate, but yields were slightly depressed by potash. Nitrogen produced a consistently lower yield, whether used alone or with other fertilizers.

The rotation experiment carried out on light gravelly soil at Bramford (1893–1907) was similar in design to the Saxmundham experiment already described, except that peas replaced beans and that for the first 8 years the root crop was swedes. Peas were grown in 6 years, but in one of these the produce was scattered, after cutting, by high wind before it could be weighed—illustrating the additional hazards which experiments with peas have to face. Fig. 3 shows that, on the average, peas gave little or no response to fertilizers, the response of peas being in each case less than that of any other crop. In the later years of the experiment, however, a small effect of nitrogen and of potash was obtained. All other crops, including clover, gave substantial responses to nitrogen and some response to potash; phosphate was ineffective on all crops.

A group of 8 recent annual experiments on green peas carried out by local workers in Bedfordshire and Worcestershire in co-operation with

Rothamsted showed on the average no response at all to nitrogen in the presence of phosphate and potash. Five experiments showed no consistent effect of phosphate, and in 4 cases out of 5 potash depressed the yield.

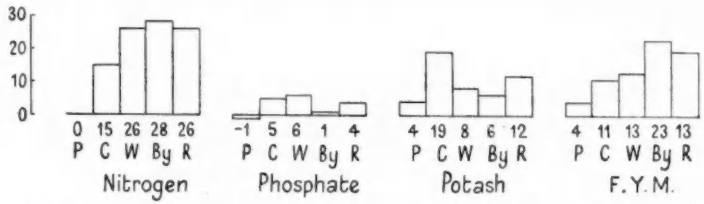

FIG. 3. Average responses of crops grown in rotation as percentage of mean yield (Bramford 1893–1907).

Key to crops:	*Rates of dressing (per acre):*
P Peas	0·3 cwt. N as nitrate of soda.
C Clover	0·3 cwt. P_2O_5 as superphosphate.
W Wheat	0·5 cwt. K_2O as muriate of potash.
By Barley	6 tons F.Y.M.
R Roots	

4. *Current Manurial Practice on Farms*

The experimental results discussed in the preceding sections suggest that beans should always receive F.Y.M. or both phosphate and potash; nitrogen appears to be of little value for beans. Insufficient experiments have as yet been carried out on peas to enable their manurial requirements to be assessed with any certainty.

With these conclusions in mind it is appropriate to review the information obtained from the Survey of Fertilizer Practice [11] on what manures are in fact used by farmers on beans and peas. The survey has recorded the amount of F.Y.M. and fertilizers applied to a large number of fields under beans and peas in the Cambridge, Bristol, and Leeds Advisory Provinces for the years 1939–44.

The extent to which F.Y.M. and phosphate are used on beans is shown in Table 6. In Norfolk and East Suffolk more than half the beans were dunged, compared with about one-third in the rest of the Cambridge province. In the west and north of England F.Y.M. was used much less frequently; only about 10 per cent. of the beans was dunged in most of the surveyed counties. The counties which used most F.Y.M. used least phosphate; thus less than a quarter of the beans received phosphate in Norfolk and East Suffolk, compared with one-half in Hertfordshire, Essex, and West Suffolk. Phosphate and dung were rarely applied together. Considerable changes have occurred in the manuring of beans since 1939, and these are shown diagrammatically in Fig. 4 for a number of counties in the Cambridge Province. In these counties the proportion of dunged fields fell from 50 per cent. in 1939 to 25 per cent. in 1942, whilst in the same period the proportion of fields receiving phosphate increased from 10 per cent. to 40 per

cent. Data for the other provinces are less reliable, but they suggest that a similar trend was in progress up to 1942.

The use of nitrogen and potash on beans in the three surveyed Provinces is also summarized in Table 6. Generally speaking, not more

TABLE 6. *Proportion of Acreage of Beans receiving F.Y.M. and Fertilizers (1942–4)*

	No F.Y.M.		*With F.Y.M.*			
	o	*p*	*o*	*p*	*n*	*k*
Cambridge Province						
Norfolk, East Suffolk	28	17	46	8	6	0
West Suffolk, Essex, Hertfordshire	17	53	23	7	20	4
Bedfordshire, Cambridgeshire, Huntingdon	38	28	27	8	4	1
Leeds Province						
Yorkshire	44	47	6	3	33	9
Bristol Province						
Worcestershire, Hereford, Gloucestershire, Somerset, Wiltshire	45	41	7	7	4	3

than about 5 per cent. of the beans received nitrogen, but about 20 per cent. was dressed in the boulder clay areas of Hertfordshire, Essex, and West Suffolk, and as much as 30 per cent. in Yorkshire. The average rate of application (0·23 cwt. N per acre) was very similar to that for cereals; about half was applied in a compound fertilizer with phosphate in autumn, and half as a top-dressing in spring. Practically no potash was applied to beans; there was in fact no allocation of potash for this crop until the 1943–4 season, but very little was applied in 1938–9 and 1939–40, before supplies were rationed, or in 1943–4, when a ration of 0·4 cwt. K_2O per acre was made available.

The Survey of Fertilizer Practice has also produced evidence on yields of beans which, although in itself less reliable, is interesting in that it fully bears out the experimental results described earlier in this paper. For example, in a recent survey of the 'highland' soils of Huntingdonshire, the average yield of beans which received no F.Y.M. was only 5·1 sacks (11·2 cwt.); the average yield on fields which received F.Y.M. was 7·0 sacks (15·4 cwt.). It is sometimes stated that since beans are in general a heavy-land crop they are able to obtain sufficient potash from the reserves in the soil; but in many districts of heavy land (e.g. Holderness, North Essex, East Hertfordshire) a rotation of wheat, beans, and fallow is common, and in this case fields often go on for many years without either potash or F.Y.M. It is probable that after many years under such a rotation considerable increases will be

obtained from the use of potash. Moreover, beans are often grown to-day on land which is low in both phosphate and potash; for example, in several counties of the Bristol Province much of the grassland which has been ploughed up consists of old meadows exhausted of both phosphate and potash by repeated haying.

It is evident from the foregoing discussion that inadequate manuring, and in particular the insufficient use of F.Y.M. or potash fertilizer, may well be one of the principal causes of the poor bean yields experienced in many districts in recent years. Farmers must be persuaded that no

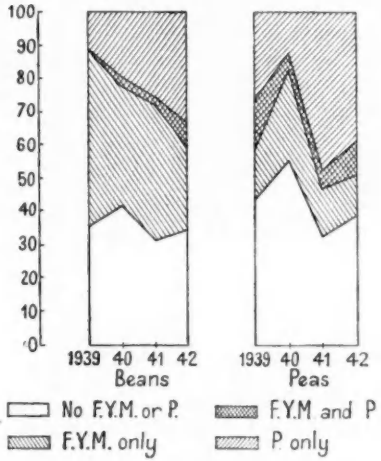

FIG. 4.

beans should be grown without receiving either F.Y.M. or both phosphate and potash, except on land in high condition. In some districts 'potassic super', a mixture of superphosphate and muriate of potash to give approx. 13 per cent. P_2O_5 and 13 per cent. K_2O, is available; for farmers who are accustomed to using compound fertilizers this should prove satisfactory for beans.

Peas were treated on an average very similarly to beans, except that they received rather less F.Y.M. and phosphate and rather more nitrogen, and most of the divergences of practice from county to county already noted for beans apply also to peas. Changes in fertilizer practice, shown in Fig. 4, are more irregular than for beans, but show the same general tendency for less dung and more phosphate to be applied; at the same time the use of nitrogen on peas in the eastern counties has increased from 20 to about 40 per cent. Unfortunately it is impossible to say at present how far farmers' manurial practices reflect the actual requirements of this crop; there is a very great need for a series of simple fertilizer experiments on peas.

Acknowledgement is due to J. S. Gregory for his valuable help in the abstraction of data.

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MILLETS IN THE MIDDLE EAST

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AMONG the cereal crops, it is rather astonishing that so little attention has been devoted to the study of the growth and improvement of the various kinds of millet that are cultivated in many countries of the old world. And yet perhaps it is not really astonishing. The millet grains take no considerable part in international commerce; they are, in all countries, the food of the poorer classes, and are little cultivated in the more advanced agricultural regions. On the other hand it must never be forgotten that they form the principal food of perhaps a quarter of the world's population. They are the dominant cereals in the whole of Africa except the north. They are grown in India on about 60 million acres with an estimated production of 12 million tons of grain. They are the mainstay of the people of northern China and Manchuria. They are specially important among the nomadic people of central Asia, and are a large factor in the cereal production of SE. Russia.

Moreover, the millets have certain advantages over any of the more usual forms of cereal. Some of them, notably the various Panicum millets, grow very rapidly and ripen more quickly than any other cereal crop. They are, hence, suitable where the rainy season is very short. Some of them resist drought in a remarkable manner and can be grown where no other summer crop can be profitably cultivated. They are less exhausting than maize and some of them will flourish on land which is too thin or too poor to grow any other cereal. They require less attention than maize, though they will pay for attention. They are attacked by few insect pests. Most of them flourish under high-temperature conditions—a very important matter in many parts of the Middle East. All these factors determine the position of the millet crops and their maintenance as important sources of human and animal food in the hotter and drier regions of the globe.

In their present distribution, however, the Middle East has only a minor place, though they are of very ancient use there. Unlike wheat and barley none of the millets seems to have had its origin in this region. Sorghum appears to have come either from India or Africa [1]. The various Panicum millets are of central or eastern Asian origin. Bulrush millet comes almost certainly from Africa [2]. *Eleusine coracana*, the *ragi* of India, which is cultivated on 6 million acres in that country, has very probably been developed there. But although all the millets come from outside the Middle East, they have been known and used there from the very earliest times. Sorghum has been found in Sennacherib's palace at Nineveh, dating from about 750 B.C. [3], and though the suggestion that it has been found in Egyptian tombs dating from 2200 B.C. is probably incorrect, yet this millet was certainly known in Egypt from a very remote period. In the prophecies of Ezekiel a grain known as *dukhn* is mentioned which may be either *Setaria italica* or *Pennisetum* sp. It is difficult to get complete data about the present status of their cultivation

with the partial exception of sorghum (*durra*), as in no case is the area under each of them separately recorded. In Egypt the area under millets, including sorghum, is between 200,000 and 300,000 acres, almost entirely in Upper Egypt. In Turkey, they occupy quite a small area compared with maize, the mean for 1940–2 being 186,000 acres with an estimated yield of 64,000 m.t. of grain, whilst for the same years over 4 million acres were under maize with a yield of 600,000 t. of grain. In most of the other countries of the Middle East, the data needed to get an exact idea of the present status of millet cultivation as a whole, relatively to other cereal crops, do not exist, though in most of them sorghum cultivation, at least, is important.

Two or three of the millets that are grown on a very large scale in other parts of the world are hardly found in our region or only on its edge. These are (*a*) Pearl or Bulrush millet (*Pennisetum typhoideum*), (*b*) *Eleusine coracana*, the *ragi* or *nagli* of India, and (*c*) *Eragrostis abyssinica*, the *Am tef* of Ethiopia. The first of these (*a*) is very largely cultivated in Nubia and the Sudan and is also grown in Arabia and Abyssinia. Beyond this it is hardly grown at present though at one time it seems to have been produced extensively in Mesopotamia. It has great resistance to drought and grows in regions with less than 15 in. of annual rainfall. It is a cereal for warm areas with low rainfall. The second (*b*) (*Eleusine coracana*) is still less common. It is occasionally met with in Abyssinia, but only the white kind is used for food, the other varieties being used for making beer. The *Am tef* of Abyssinia (*c*) is locally important, and forms a very usual article of diet in the country. It grows on thin and dry soils and ripens in 50 days. Both brown- and white-seeded types are cultivated; but this grain has not spread beyond its borders in the Middle East. On the other hand, the crop has been taken to South Africa where there are now 500,000 acres under cultivation, almost entirely as a fodder crop [4].

In view of their limited distribution, I shall, however, say no more of these three millets in the present paper.

Sorghum or Great Millet

By far the most important of the millets is *Sorghum vulgare* or the Great Millet. The two grand regions for sorghum culture are Africa and India, with a subsidiary but important area in north China and Manchuria. But in most of the countries of the Middle East, sorghum is grown and valued as an irreplaceable element in the cultural system. It disappears in the extreme north of the area, and is also hardly found at high elevations. This may be due to the absence of a sufficiently high temperature during the growing season, for the Americans have found that in the U.S.A. it is successfully grown only where there are at least 160 days free from frost, where the rainfall is 18–40 in., and the average July temperature is above 76° F. [3]. It is hence unimportant on the Persian plateau and in Afghanistan, whilst in Turkey it is rarely found in the northern part of Asia Minor or in the high lands of Armenia.

The main advantage that sorghum has over maize is that it requires less rainfall. Where there is abundant water, the tendency is for sorghum

to be gradually replaced by maize, as has happened in Egypt. But in a country liable to small or poorly distributed rainfall, the sorghum plant has the faculty, not possessed by maize, of remaining dormant during short periods of drought, whereas maize would be killed or greatly damaged. This is a very important quality in countries where such poor distribution of rain is likely to occur during the growing period. Further, sorghum is less exhausting than maize; for example, it has been found in Palestine that although legumes must be grown after maize, a second cereal crop can be taken after sorghum [7]. The superiority of sorghum to maize in a region of limited rainfall is shown by the fact that the water-requirement, per pound of dry matter produced, is less than for any of the common grains; for example, to give one pound of dry plant wheat requires 513 lb. of water, barley 434 lb., maize 368 lb., but sorghum only 322 lb. [6]. Further, long ago Hilgard [8] reported that whilst maize is rather sensitive to alkali in land, sorghum will succeed on white alkali soils. This is important in regions where the concentration of salt in the soil is bound to be considerable even if it does not appear as an incrustation.

The sorghum grain is not capable of making good bread with yeast when used alone, though it can be mixed to the extent of 20 per cent. with wheat without spoiling the bread. On the other hand, it grinds easily, is economical in use, and can be eaten as a porridge or in unfermented bread, as is common in tropical countries. It is an excellent food for animals and in some of the countries of the Middle East (Palestine, Transjordan, Syria, Lebanon) it is said that 50 per cent. of the crop is so consumed [9]; as animal food, tests indicate that it may be about 89 per cent. as efficient as maize [10].

One of the great advantages of sorghum as a crop is that the straw, even after the grain is ripe, remains a good fodder—far better than that produced by maize. Sorghum straw is, in fact, the principal fodder of cattle in a very large part of India and in every country where sorghum is grown for grain. The leaves remain green much later than do those of maize. None of the other millets is as useful for this purpose as sorghum and, though there is danger in feeding fodder from immature or stunted plants (owing to the possibility of poisoning), there is nothing against the mature straw. Of course, sorghum can be grown for fodder only, when it is cut while the grain is in the milk-stage. Special varieties are kept for this purpose in India and also in Egypt, and it has been stated with truth that no other crops can compare with the sorghums in yielding a heavy weight of green fodder of good quality [11].

Except in NE. Africa and in Arabia, practically only two types of sorghum are grown extensively in the Middle East. These belong to the species *Sorghum durra* and *S. cernuum* [1]. In N. Africa and the Sudan many other forms occur and are cultivated, but these two (which are very closely related) seem to be almost the only ones which have penetrated, as cultivated plants, into the greater part of SW. Asia. In both these types the panicle is shorter and more compact than in most other varieties. The grains are not large and are flattened, whilst the tip of the stem is often curved so that the head hangs down in a way that is called

'goose-neck'. One of the reasons why these types alone have continued in our region is that they ripen fairly quickly, i.e. in 80–110 days, if grown in the hotter part of the year. This is very important, for most of the other common sorghums of NE. Africa and SW. Arabia are much later in ripening [12]. Except in Egypt, where irrigation facilities are universal, the qualities mainly desired are: (1) short plants, not more than 2 m. high, (2) early ripening plants, not needing more than 3 or 4 months to mature, (3) very dense heads with grains full at the top and the bottom, and (4) a high yield of grain.

We may now consider the status of sorghum cultivation in each of the more important countries of the Middle East.

Egypt.—The cultivation of sorghum for grain is of very old standing; now there is a tendency for its decline and for it to be replaced by maize; it is almost restricted to Upper Egypt. There are two common types, both of them forms of *Sorghum durra*, the first of which is known as *sefi* and is grown in summer, being sown in March or April and reaped in August, and the second, known as *nabari*, sown in August and reaped from October to December. The yield in both cases may go up to over 2,000 lb. of grain and about 8 camel-loads of fodder per acre. From figures given by Dudgeon, the mean yield of the sorghum crop for the whole of the country would appear to be over 2,000 lb. per acre. During the recent war, however, the yield per acre went down by over 18 per cent., chiefly due to the shortage of fertilizers.

The crop is not badly attacked by pests. Borer (*Sesamia*) may be serious but is not increasing. *Aphis sorghi* has been described as the most serious pest of sorghum, but in Egypt it is only of local importance [13]. Among diseases, grain smut is by far the worst and is almost universal though it can easily be checked by seed-treatment. Birds are perhaps the most troublesome enemy of the crop, which has to be carefully watched when it is near ripening.

The grain is very little used as food in Lower Egypt, but is the main cereal of the people in Upper Egypt. It is generally used mixed with wheat, barley, or beans. Half sorghum and half beans makes the food of the poorest people [13].

Sorghum forms 10 per cent. of the cereal acreage of Egypt [9], where the estimated total production is about 300,000 tons. A small amount is exported, and about 20 per cent. of the production is used for feeding animals.

Palestine, *Syria and Lebanon*, and *Transjordan*.—In these countries sorghum is a very important crop, but in none of them is it so vital as in Palestine where it forms 23 per cent. of the cereal acreage (in Transjordan 5½ per cent. and in Syria and Lebanon 8½ per cent.). The total production is estimated to be about 51,800 tons in Palestine, 7,700 t. in Transjordan, and 86,000 t. in Syria and Lebanon. Of the amount available for use in these countries, about one-half is used for animal feeding [9].

In all these areas the goose-necked form of sorghum is almost universal. In Palestine, in the majority of the areas where summer crops can be grown without irrigation, sorghum is probably the only remunerative

crop. In years of sparse spring rainfall, *durra* (i.e. sorghum) can be grown where maize would fail, and south of a line from Jaffa to Nablus it is probably the only paying cereal crop [7].

In *Turkey*, sorghum is cultivated chiefly in western Anatolia, especially in the valley of the Buyuk Menderes, in the vilayets of Aydin and Mugla. In this region it is one of the essential cultivations. In other parts of the country, it is only sown locally, but in the Taurus the fields of sorghum become frequent. The most common type of sorghum is that already described as being usual in SW. Asia, but kafir corn (*Sorghum caffrorum*), both with a red and white pellicle, is common. Sorghum grain is ground and made into cakes, and is also largely used as a food for stock.

In *Iraq*, sorghum is cultivated extensively as an irrigated crop in summer in the riverain areas between Basra and Mosul, especially along the Euphrates. Cultivation increased considerably in the years before the recent war, as the grain is 'well liked by the people as food for human consumption' [16]. It forms about 9 per cent. of the cereal acreage and the production before the war was estimated at about 140,000 t., about 25,000 t. of which were exported. About 30 per cent. of what is produced is fed to animals, and the remainder is used as human food.

In *Persia* and *Afghanistan* the crop is of very minor importance. There is a small amount of sorghum grown in most parts of Persia, but especially on the plateau, though it is not in any way a staple of the country. In Afghanistan it is still less important.

Arabia is one of the very ancient homes of sorghum cultivation, and the crop is grown everywhere, both for grain and as a fodder crop, in the latter case under irrigation. In Aden a recent authority states that the main dry-land crop is sorghum, and that it gives from 400 to 600 lb. of grain per acre; for value as food and fodder it is unlikely that any crop can compete with it [17].

Panicum Millets

Though sorghum may perhaps be considered as the most important of the millets, yet there is another class which is at least as widespread in the Middle East, but cultivated in a very different part of the area and under very different conditions. This is the class of the Panicum millets, which were probably developed in eastern or central Asia, but which have spread into all tropical and semi-tropical countries where the rainy season is short, where the soil is thin and poor, and especially where a crop is wanted that with very little effort can be relied on to give a fairly large amount of fodder as well as grain. The northern limit of the cultivation of these essentially semi-tropical crops appears to be about a June isotherm of 63° F., or possibly a July isotherm of 68° F.

There are four important species of this type of millet:

1. *Panicum miliaceum*, the common *proso* millet of Russia, has now spread far, not only in the Middle East but also in India and in the U.S.A. where it was probably introduced by Russian immigrants. The head of this millet consists of a large open-branching panicle somewhat like that of oats. It has coarse, hollow stems usually about 30 in. high. It is sensitive to frost and so should not be sown till late in the spring

when the ground is warm and if possible moist. It grows slowly at first, but with increasing heat comes on very rapidly and ripens in from 50 to 60 days from sowing under favourable conditions. It seems to have the lowest water-requirement of any grain crop (310 lb. of water per pound of dry matter produced) [6]. Its roots are very shallow. It grows well on any kind of soil except coarse sand, and is well adapted to plateau conditions and high elevations. In dry areas only 22 lb. of seed per acre are needed for sowing, with a little more in damper conditions. It is not usually considered suitable for irrigation, though in central Asia it is irrigated [18]. The straw does not make the best of fodder and even the hay made from the flowering plants is poor. The ripe crop easily shatters the seed and hence it is usually cut when the upper part of the ear is still green.

The yield of grain under the conditions where it is usually grown—on poor thin soil without manure, after another grain crop—is from 400 to 750 lb. per acre, though as much as 2,000 lb. have been obtained under favourable conditions. When used for human food, it has an agreeable taste with a slight nutty flavour. The meal is cooked into a mash or porridge. Mixed with four times its weight of wheat, it makes a good substitute for wheat alone. For animal feeding it appears to be rather better than oats and not quite so good as barley.

The best types of *proso* millet for the Middle East are probably those from SE. Russia, where alone, till very recently, any effort has been made to improve the type of crop grown. The Russian varieties are said to be much earlier than those from China or India, and this is a great advantage with a crop whose value lies largely in its early ripening.

2. *Panicum miliare* or the Little Millet. This millet is often confused with (1), and hardly deserves separate mention, for it is apparently grown in the Middle East on a very small scale, though it is extensively cultivated in India, chiefly in the south. It is noteworthy, however, for its reputation of growing on the poorest, otherwise worthless lands. It can withstand both drought and waterlogging. It grows in India up to 7,000 ft. elevation, and, there, needs 3½ months to mature [20]. The yield is not widely different from that of *proso* millet.

3. *Setaria italica*, also known as *Panicum italicum* or *Chaetochloa italica*, the well-known Italian millet, is grown on almost as large a scale as the *proso* millet, either as a crop or an admixture. In Japan it is the most important millet in cultivation. Its chief advantage over *proso* millet is that it not only gives a good yield of grain (though the grain is not so good for any form of bread as is *proso*), but also the straw forms an excellent fodder. If grown exclusively as a fodder crop and cut when in flower, it makes excellent hay. It is also not so exacting in the matter of climate as *proso*. Chiefly for these reasons it has enormously extended in the U.S.A. [21], almost entirely as a heavy yielding, rapidly growing forage crop. The hay is stated to be better than timothy hay.

Like *proso* millet, it should not be sown till the land is warm, and a little later than maize. It usually ripens somewhat later than the *proso* millets, but can be cut for grain in from 70 to 90 days after seeding. A

good crop will yield about 800 lb. of seed and 2,500 lb. of straw per acre, and may stand 5–6 ft. high; heads of grain 7 in. long have been recorded, though the average is much less than this. It will grow on very poor land, but will not stand waterlogging or a long drought. It lacks the ability possessed by sorghum of recovering after a period of drought.

4. *Echinochloa frumentacea*, also known as *Panicum frumentaceum* and *Panicum crusgalli*, called by some authors Poor Man's Millet, can hardly be considered as a crop in most of the Middle East, though it occurs almost everywhere where the other Panicum millets are found, often as a weed. I mention it because it is the quickest growing of all the millets and has been known to give a crop of ripe grain in 45 days after sowing, under favourable conditions of moisture and temperature. When grown it is sown in the middle of June when the soil is moist. Rain is needed till the middle of August, when it is cut. This presupposes a monsoon climate with rain in summer, and, apart from irrigation, it seems very doubtful whether there is much place for this millet in the greater part of the Middle East.

Such are the chief varieties of Panicum millet to be found in our region. What is their status at present and their future possibilities? In Egypt, the so-called Poor Man's millet, i.e. *Echinochloa frumentacea* (Arabic *dineba*), is used as a reclamation crop on lands too salt for rice. It is chiefly found in Behera and Fayum, and is rarely grown except for the above purpose. It is usually considered to need plenty of water, but to have the capacity of standing drought. It yields about 10 bushels (say 510 lb.) of seed per acre, but is generally treated as a fodder crop and cut for this purpose [22].

In Turkey, almost the only one of this class of millets is *proso*, though it is often very much mixed with Italian millet. This is met with in many districts but most largely in SE. Anatolia, though it is also cultivated in the south-west. In central Anatolia (Konia), *proso* is likewise grown, and, generally, it is used where the soil is very shallow [15]. In the areas between Turkey and Russia, both Italian and *proso* millets are grown. In Georgia, for example, *proso* is by far the most common though it is commonly very much mixed with Italian. Even now, the chief food of the people in W. Georgia is a thick porridge cooked from one of these two millets [23]. In the high lands of Armenia, Italian millet supplants *proso* in dry years and in exhausted soils and becomes an independent crop.

In Iraq, on the middle Euphrates zone south of Baghdad, *proso* millet is cultivated along with cotton, sesame, and gram as a hot-weather crop between March and September [24]. It is specially prominent along the Shatt-el-Hai river. Other forms of millet are generally looked on merely as forage grasses or as weeds, though *Echinochloa frumentacea* is occasionally cultivated for its seed.

In Persia, most of the Panicum millets are found, particularly in the north-east of the country, though they do not appear to make a very large contribution to the food supply. In Afghanistan, *Panicum miliaceum* is grown all over the country by the sedentary population as well as by

nomads, and quite a large number of its varieties are found there. It is usually mixed with Italian millet and, especially in the high mountain districts, it is difficult to tell which forms the principal crop. *Echinochloa frumentacea* is found only as a weed in rice fields [25].

General Conclusions

This summary of the present position of the millets in the agriculture of the Middle East would not be complete without some consideration of the future. There seems little doubt that there is scope for a much more extended use of sorghum as a crop in areas where maize can hardly be grown owing to the shortness and uncertainty of the rain. I doubt whether sorghum has much future under irrigation-cultivation except possibly as a pure fodder crop, for the only advantages that sorghum possesses are its capacity to flourish where water and manure are short and where the attention that maize requires cannot be given. On the other hand, the market for maize is a better one, for its grain is usually preferred both for human food and for animals.

But where irrigation is not available and rainfall is short, sorghum seems the food crop *par excellence* for the summer in the hotter countries, just as wheat and barley are the natural autumn and early spring crops. But in order that the extension of which sorghum is capable should take place, there will have to be a great deal of selection or production of the most suitable types with a capacity to ripen early, with a somewhat dwarf habit, with dense heads and consequently a high yield of grain. There is an opening for the development of such types in all the countries of the Middle East, excluding those which are entirely in plateau country. Efforts in this direction have been made in Egypt, but they are still more required in other parts of the region where dry cultivation prevails necessarily over the greater part of each country.

The place of the Panicum millets in the agricultural systems of the future seems still more certain if only the best types are evolved and brought into general cultivation. There is real need of food and fodder crops that grow under high temperature conditions, ripen quickly, and grow on poorer land than the alternatives available. The Panicum millets have too often been, in the past, considered as nomads' crops which would tend to disappear as nomadic life became less usual. But the experience in SE. Russia shows how they can be a dominant feature in agricultural life under conditions where it would be almost impossible to grow profitably any other cereal crop. The experience in the U.S.A. also goes to prove that they have their place in advanced agriculture, though, there, they are chiefly forage crops. But to achieve their place on the plateau lands of SW. Asia, these millets will have to be much more closely studied than they have been in the past, and the very great admixture of one type with another (as of Italian with *proso* millets) will have to be reduced or entirely eliminated. But I can picture millions of acres in the Middle East, now looked upon as useless even to a peasant agriculture, being brought at least into subsistence cultivation by the proper use and extension of the growing of the Panicum millets.

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SOME CLIMATIC FACTORS DETERMINING HIGH YIELDS OF POTATOES

PART I. TEMPERATURE AND LENGTH OF GROWING-SEASON

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THE potato is unusual in its reaction to temperature. It needs a cool growing-season, but is intolerant of anything but a trace of frost. Like the potato, carrots, lettuce, parsnips, spinach, beet, peas, turnips, cabbages, cauliflowers, and Brassicae generally—to mention only vegetable crops that are grown as annuals—need a cool season, but, unlike the potato, can all stand a fair amount of frost at one period of growth or other. Like the potato, tomatoes, peppers, egg-plant, sweet-potatoes, sweet-corn, cucumbers, squash, pumpkins, and melons of various kinds are intolerant of frost, but, unlike the potato, do well in a warm season. Other vegetables, like the onion and its relatives, are adapted to a wide range of temperatures and stand frost in certain circumstances. But the potato, almost alone among vegetables, is restricted in its temperature-requirements on both sides; for good yields it needs a season that is cool yet frost-free, and long enough for those late-maturing varieties which are the best producers.

A long, cool growing-season free from frost is characteristic of practically only two types of situation. It is found at high altitudes in tropical or sub-tropical latitudes, where high altitude ensures coolness, and nearness to the equator prevents great seasonal variations in temperature; or in maritime climates at high latitudes, where high latitude makes for coolness, and the sea is the buffer against great temperature changes. The Andean potato centre is an example of the first type, the island of Chiloe, in south Chile, an example of the second. These two centres —the two ancient homes of the potato—which at first thought may seem so different are in fact united by the common feature of fitting the peculiar temperature requirements of the crop, and have an essential similarity which the recent discussions on photoperiodism have managed to obscure.

How has the potato fared outside S. America? In the British Isles and NW. Europe the climate is maritime, like Chiloe's. The conditions of temperature are those to which its ancestry has accustomed the potato, and it is not surprising that the world's record for yield was put up in Ireland and that the highest average yields are found in the Netherlands. But in NE. Eurasia and most of N. America, where the potato is grown on a vast scale, the climate is continental. In these continental climates at high latitudes the seasons may be either cool or long, but not both cool and long. In them the potato meets a situation to which it is not used, and our first problem is to determine how the crop is affected and what the chances are of overcoming the difficulties by breeding. No apology is made for treating the subject in some detail. It is occasionally stated vaguely in the literature that the potato is a maritime plant

unsuited to a continental climate—a statement which is wrong on both scores—but so far as the writer knows there has been no analysis of the difficulties peculiar to continental climates beyond subtropical latitudes.[1]

If our first problem is that of a climate to which the potato is not fitted by its ancestry but in which it is widely grown, our second is in a way the converse. In Africa and southern Asia there are stretches of country at low latitudes and high altitudes. The climate is essentially like the Andean, and one would have expected the potato to have been more widely cultivated than it is. Our problem here is to inquire in what way there has been a failure to make better use of the advantages of an ancestral type of climate, in the hope of adding to the food supplies of regions in which other calorie crops do not always do well.

The potato in maritime and continental climates at high latitudes.—By way of illustrating the difference between a cool maritime and a cool continental climate, consider a series of towns running west to east, in which the mean temperature for July is not far from 60° or 65° F. In Dublin the mean for July is 58·4° F., and for January 40·2° F., so that the drop in mean temperature from July to January, i.e. from about midsummer to midwinter,[2] is 18·2° F. At Cambridge the mean for July is 61·7° F., and the drop to January 22·7° F.; at Amsterdam the mean for July is 63·0° F., and the drop 25·5° F.; at Berlin 64·4° F., and the drop 34·2° F.; at Warsaw 65·4° F., and the drop 39·7° F.; at Minsk 63·5° F., and the drop 43·7° F.; at Moscow 64·4° F., and the drop 51·8° F.; and across the Urals the change from summer to winter is even greater. From west to east in a zone where midsummer temperatures are more or less the same, the winters get colder and colder, and the growing-season correspondingly shorter and shorter.

For quantitative information on the relation between midsummer temperatures and the length of the growing-season in a northerly continental climate one may use some figures from N. America. Here the climate is mostly continental. As in Europe, the sea's influence is strong in the west but mountains limit a maritime climate to a relatively narrow strip along the Pacific coast, and over the rest of Canada and the United States the climate is predominantly continental, even in the potato-growing sections of New England and neighbouring parts of Canada near the Atlantic. Two places are given as illustrations: Aroostook County, Maine, and N. Dakota. Aroostook County is chosen because of its fame as a potato-growing area; cultivation is more intensive and yields per acre higher than elsewhere in the United States. N. Dakota is not renowned for its potatoes (though it grows good crops of early or medium-early varieties like Triumph, Irish Cobbler, Early Ohio, and Chippewa), and is chosen because its climate is typical of high-latitude continental plains away from the mellowing influence of the sea or great lakes. Information

[1] Other types of climate like the Mediterranean present their difficulties, but it would bring out no useful point to discuss them here.

[2] The use of July and January to represent midsummer and midwinter is accurate enough for continental climates, but in maritime climates temperatures lag a little behind, so that the warmest part of the year is about the end of July or beginning of August. The bias which this introduces is negligible for this discussion.

about these places is given in Table 1: it comes from the *U.S. Yearbook of Agriculture for 1941*.

To interpret the information in Table 1, one may take the optimal temperature for tuber-formation to lie between about 60° and 64° F., and accept that the limit for really efficient production is reached when the mean temperature of July is as high as 70° F. (although it is of course possible to get crops of a sort at higher temperatures). Evidence about the first point has been collected by Bushnell [1], Werner[2] and others. The second point was established by Smith [3], who found in a survey of the United States that the highest yields were obtained north of the 70° F. isotherm for July. These figures are for long days. Under short-day conditions the yield is less sensitive to heat; this is evident from Driver and Hawkes' review of the literature [4].

TABLE 1. *The Relation between the Mean Temperature for July and the Average Length of the Growing-season between the last Killing-frost of Spring and the First of Autumn. Data for Aroostook County, Maine, & N. Dakota*

	Aroostook County, Maine		*N. Dakota*		
				Growing-season	
Mean temp. for July ° F	*No. of stations*	*Growing-season (days)*	*No. of stations*	*Range among stations (days)*	*Average of all stations (days)*
64·1–65	1	107	..	..	..
65·1–66	1	109	3	110–17	112
66·1–67	..	..	6	102–28	113
67·1–68	1	117	11	104–31	116
68·1–69	..	..	14	109–32	119
69·1–70	..	..	18	109–33	120
70·1–71	..	..	21	113–40	125
71·1–72	..	..	7	120–38	128
Over 72	..	..	2	124–32	128

The summers in Aroostook County are cool, and the temperature suitable for tuber-formation, even if in midsummer they are a shade above the optimum. But, as is usual in high-latitude countries with a continental climate and a summer cool enough to favour potatoes, the season is very short, only 107 to 117 days.[1] This is insufficient for late varieties of the type grown in western Europe; e.g. in Britain about 175 days must be allowed from time of planting for a late variety to mature. These figures are not on a strictly comparable basis because those given for Maine refer to the time from frost to frost, not from planting to maturity. To bring them into line one must reckon the growing-period in Aroostook County from the date of planting, which is from about May

[1] As illustrations of how different a maritime climate is, Seattle, Washington, at much the same latitude as Maine, has a growing-season of 255 days with a mean temperature of 63·1° F. in July, and Eureka, California, an area on the coast with a local reputation for seed, has a growing-season of 328 days with the mean for July as low as 56·1° F.

10 till early June [5], to the average date of the first killing frost in autumn, which at four different stations in Aroostook County is from Sept. 4 to 22 This gives a growing-period of about 4 months. Even if allowance is made for the way speed of maturity varies with differences of climate, the growing-season in Aroostook County falls far short of the needs of a late-maturing variety from western Europe.

The length of the growing-season in the cooler parts of N. Dakota is like that in Maine. Warmer stations have longer seasons, but the gain is small; for each 1° F. rise in the mean temperature for July, the season is increased by only about 3 days, and even in stations with a mean temperature in July of 70° F.—about the upper limit for efficient production when the days are long, as we have seen—the season is still only about 120 to 125 days from frost to frost.

The absence of a long, cool growing-season in a high-latitude continental climate is associated with low yields. To use figures calculated from the data given by Ritchie [6], the average yield in Canada for the years 1933 to 1937 was 134 bushels (of 60 lb.) per acre, in the United States 111 bu. per acre, and in the U.S.S.R. 124 bu. per acre. These are the three countries at high latitudes with the most markedly continental climate. By contrast, the countries in or bordering on the NW. Atlantic, Norway, Sweden, Denmark, Scotland, England and Wales (as a unit), Northern Ireland, Eire, and the Netherlands had average yields of 266, 213, 245, 263, 247, 248, 283, and 298 bu. per acre respectively. Since the plains stretch uninterruptedly inland from the North Sea, a sea-atmosphere penetrates fairly far from the coast in Europe; in the cool areas of Germany, for example, the season is still long enough for varieties which are fairly late even by western European standards, and the average yield in Germany from 1933 to 1937 was as high as 240 bu. per acre.

Although land temperatures at high latitudes must be influenced by the sea if high yields are to be obtained, it does not follow that the best conditions are found where the sea's influence is strongest. There is probably a limit, beyond which a more intense influence is harmful. The air becomes too humid (although excessively high humidity will become less important as blight-immunes are bred), the rainfall often, but not always, too high, the soil leached and poor, and the landscape changed by erosion. It is not within the scope of this discussion to labour these points; as illustrations of their validity, one need only note that although the maritime influence is strongest in the west of England it is the east that grows most of the potatoes, or that the west coast of N. America and western Tasmania, both areas with a strongly maritime climate, are not important centres of potato culture.

The possibility of improving yields in high-latitude continental climates by breeding.—In looking for qualities in *Solanum tuberosum* which can effectively cope with the incompatibilities of a high-latitude continental climate, one feels that if these qualities had existed they would already have been brought out by breeding. Perhaps the requisite qualities can be found in some other species of *Solanum* and introduced into the potato by breeding. A growing-season of suitable length and temperature might be obtained in a high-latitude continental climate by intro-

ducing resistance to heat, perhaps from species like *S. phureja*, on the one hand, or by introducing resistance to frost from species like *S. acaule*, *S. demissum*, *S. Bukasovii*, or *S. curtilobum*, on the other. Frost-resistance, in particular, has often been discussed, but the point which is in danger of being overlooked is that the species which are likely to be of use are all from tropical or sub-tropical latitudes, and there is no reason for believing that they, or crosses between them, will be any more successful in high-latitude continental climates than *S. tuberosum* itself. It would, for example, not help the yield if, by introducing resistance to frost, one reduced at the same time the optimum temperature for tuber-formation by a corresponding amount. In this case frost-resistance would allow cultivation to be shifted to higher latitudes—admittedly a point of great value to Canada or Russia—but it would leave untouched the problem of raising the ceiling of productivity per acre and bringing yields more into line with those of cool maritime climates. Unfortunately, there are no data for a profitable discussion of this matter; all that we can do is to make the most hopeful assumptions—that tolerance of heat may be obtained without losing tolerance of cold, and that resistance to frost will involve no lowering of the optimal temperature for tuber-formation—and see what the prospects are.

Table I shows that in the type of continental climate represented by N. Dakota the growing-season is increased by about 3 days for every 1° F. increase of temperature at midsummer. One may, therefore, reasonably assume as a rough guide that in a high-latitude continental climate like N. Dakota's raising the optimal temperature of the crop by 1° F. will adapt that crop to a growing-season which is about 3 days longer. Raising the optimum by 5° F. from 60–65° F. to 65–70° F., which is likely to be quite a big rise to attain, would still leave the growing-season very short, as Table I shows. One might perhaps hope that higher temperatures would hasten maturity by some process akin to that underlying Livingston's law, and so reduce the period which is needed for growth. But this would require the validity of our first hopeful assumption because, by Livingston's law, there would be no gain if the minimum temperature for the growth of heat-resistant species and hybrids rose with the optimum temperature for tuber-formation.[1]

For a discussion on frost-resistance reference will be made to two particular cases, which are probably quite representative: Presque Isle, Aroostook County, Me., and N. Dakota.

In Presque Isle the average date of the first killing frost in autumn is Sept. 14. This is just an average date; because of variation from year to year plants are killed as often as not before this date.[2] To get a grow-

[1] Livingston [7], among others, regarded maturity as largely a question of acquiring the proper number of 'heat-units'. Whether his ideas as a whole can be applied to potatoes need not be discussed, but at least that part of his hypothesis which uses the minimum temperature for growth as a base on which to calculate the number of 'degree-hours' seems reasonable.

[2] No figures are available in Pretoria to show the variation in frost dates in Aroostook County, but in Orono, Maine, where the growing-season is longer and warmer, the date has varied from Sept. 9 to Oct. 20 in the course of 40 years, the average date being Sept. 25.

ing-season comparable with that of a medium-late maincrop variety in NW. Europe, the average date of the first killing temperature would have to be set back to at least Oct. 15, which would often mean killing-temperatures in the first half of October but rarely in September. Between Sept. 14 and Oct. 15 the mean minimum temperature at Presque Isle drops about 9° F. (5° C.), and this is roughly the measure of the frost-resistance which would be needed. There is no evidence that it exists in any species. Even *S. acaule*, the most resistant potato species, is severely damaged at −3·5° C. at the end of the season [8], though it is more resistant when young.

In N. Dakota the daily minimum temperatures fall at the rate of about 1° F. in 3 days just after the first autumn frost, so that the maximum extension of the growing-period in autumn by incorporating the full measure of frost-resistance in *S. acaule* would be roughly 20 days.[1] This estimate assumes that *S. tuberosum* has no resistance at all, which is not quite correct.

The rate of change of daily minimum temperatures is roughly the same just before the last frost of spring as just after the first of autumn, but circumstances are otherwise different. *S. acaule* possesses greater resistance to cold when the plants are young and can then stand 7° C. (12·6° F.) of frost without serious injury. *S. demissum* and some other varieties stand 5° C. (9° F.) of frost. But in spring frost-resistance is not always the important factor. If the winter snowfall is high the time of planting is governed by the ability to prepare the soil after the thaw and plant the seed; this is so in Maine, for example, and getting the soil fit for use determines the date of planting more than the danger of spring frosts. In such conditions frost-resistance is of limited importance. Even in drier areas the use of frost-resistance in spring is not without its difficulties. If potatoes were bred with the resistance of *S. acaule*, full use of such resistance could be obtained in high-latitude continental climates only by planting when the daily mean (not minimum!) air temperature was about 32° F.[2] To prepare the soil and plant the seed at this temperature, with all the problems of ice and thaw, would introduce some agronomic problems of considerable difficulty. Moreover, the frost-resistant potato would have to behave quite differently from *S. tuberosum* in its physiology of sprouting in order that emergence would not be delayed by the cold soil; without this difference the seed would lie dormant until the soil temperature at seed-level rose to about 45° F.

[1] The writer is indebted to the Climatic Section Director of the N. Dakota Weather Bureau for a table of the mean monthly minimum temperatures at different stations.

[2] One may arrive at this figure in several ways, of which this is the simplest: In the U.S.A. early potatoes are planted when the mean temperature reaches 45° F. [9]. With a potato possessing resistance to 12·6° F. of frost, planting could take place when the temperature was correspondingly lower, i.e. when it was about 32·4° F. This method involves several simplifications: it assumes that minimum temperatures change at the same rate as mean temperatures, and ignores the fact that the rate of seasonal change of temperature is not constant. A corrected estimate would put the figure somewhat lower than 32° F.

It seems that enthusiasm has obscured the limitations of the new material made available for breeding in the last 20 years, and it has not been adequately appreciated that frost-resistance on the equatorial Andes is a very different matter from frost-resistance at high latitudes in continental climates. On the Andes frost-resistance permits cultivation at higher altitudes, and, because there is practically no seasonal change of temperature, the gain is held throughout the year. But at high latitudes in continental climates temperatures rise sharply in spring and fall sharply in autumn, and the gain, being dependent on the rate of change of temperature as the season begins and ends, is relatively small. It seems, in fact, that the same great seasonal changes of temperature which limit the yield of *S. tuberosum* in high-latitude continental climates are likely also to cramp the prospects of breeding with other species.

To avoid misunderstanding it is repeated that the concern of this discussion is with high yields, and breeding for frost-resistance is being considered purely as a means of attaining high yields like those in cool maritime climates. The use of frost-resistance to shift the zone of production to higher latitudes without increasing the limit of yields is outside the scope of this paper.

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